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A critical note on meal criteria in pigs: Which behaviours do they perform during feeder visit intervals?

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ABSTRACT

The feeding behaviour of pigs can be continuously recorded using sensors, providing promising avenues for automatic monitoring of pig performance and welfare. To utilise this potential, however, the data must be cleaned and aggregated meaningfully. A common aggregation is from visits into meals, in which visits separated by intervals shorter than a meal criterion (s or min) are merged. Methods to determine the criterion and the criteria themselves vary widely between studies, and have been applied indiscriminately or only when no pen mates visited the feeder during the interval. Aggregation choices should be biologically relevant, but there is no empirical knowledge on how pigs behave during these intervals or how the intervals are influenced by feeder competition. This study had three aims: 1) test the method that classifies intervals using a three-part probability density function (short, intermediate and long intervals); 2) determine whether feeder competition differed between interval types and application methods; and 3) describe and compare the behaviours of pigs between intervals. Visit intervals were obtained from 110 barrows in ten pens with one IVOG® electronic feeding station each. A three-part probability density function was fitted to the log-transformed intervals, and its fit was assessed visually. For each pig, a short and an intermediate interval were selected for behavioural observations from camera. We found that pigs had relatively more intermediate intervals (1–28 min) than cows and that the fit of the three-part function was suboptimal. Nevertheless, identified meal criteria were in similar ranges as for other species. Intermediate intervals were more often initiated by displacements than short intervals (≤1 min), and there was more aggression and less pen exploration if pen mates visited the feeder during these intervals. Short intervals reflected interruptions in feeding behaviour, shown by standing (e.g. vigilance/chewing outside the feeder) and pen exploration (e.g. rooting, searching for pellets), while intermediate intervals contained non-feeding behaviours, such as social nosing, drinking and, predominantly, lying inactive. We conclude that intermediate intervals indicated completed feeding bouts, while short intervals reflected continued feeding-focused behaviours. Therefore, only visits separated by short intervals should be merged into meals. The exact criterion depends on the dataset but may, considering the suboptimal fit of the function, be more precisely determined using other methods. Whether visits should be merged indiscriminately or only when no pen mates entered the EFS during the interval depends on whether competition effects are of interest in the study.

1. Introduction

Growing-finishing pigs (*Sus scrofa domesticus*, hereafter 'pigs') are typically fed *ad libitum* via (automated) concentrate feeders, and obtain their daily intake via sequential visits to the feeder. Using radio-frequency (RFID) antennas, electronic feeding stations (EFSs) or computer vision, aspects of these visits can be continuously recorded, such as the feed intake, feeding frequency, duration and rate. These data could be used to monitor production efficiency (Reyer et al., 2017), health and welfare (reviewed by Bus et al., 2021), but must first be cleaned of errors and aggregated in a relevant manner. One common aggregation step is to merge visits separated by short time intervals into meals, defined as clusters of visits interrupted by short pauses (Maselyne et al., 2015).

Meals are thought to represent feeding behaviour and motivation more meaningfully than visits (Howie et al., 2009; Tolkamp et al., 1998). During the pauses within a meal, animals may still be occupied with the idea of feeding but are performing other feeding-related behaviours, such as drinking, queuing or competing for the feeder

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(Maselyne et al., 2016). Theoretically, intervals between meals should be relatively long, because after feeding satiety should gradually reduce until a new meal is initiated (reviewed by Maselyne et al., 2015). In reality, however, intervals between sequential visits can range from a few seconds to several hours, with the majority of the intervals being in the range of seconds (Tolkamp et al., 2011). Merging visits into meals mediates this discrepancy.

Visits are combined into meals based on a chosen meal criterion (Tolkamp et al., 1998). All visits separated by an interval shorter than the meal criterion are accumulated into a meal. In pigs, many methods to determine meal criteria have been used, leading to a range in applied criteria from 30 s to 47 min (reviewed by Maselyne et al., 2015). Such differences between studies causes difficulties in comparing study results, as meal criteria impact the structure of the data via feeding frequency, duration and rate (Hansen et al., 1981; Howie et al., 2010, 2009; Kissileff, 1970). In addition, if interval lengths consistently differ between pigs, some individuals may be more impacted by certain meal criteria than others, which artificially induces differences between pigs. Therefore, a standardised, biologically-relevant method to determine meal criteria is required.

The theoretically most objective method to determine a meal criterion (Maselyne et al., 2016) was originally developed from automated roughage feeder data in dairy cows (Tolkamp et al., 2000; Tolkamp and Kyriazakis, 1999; Yeates et al., 2001). It fits a probability density function with two Gaussian and one Weibull functions to the log-transformed visit intervals (Fig. 1). Each of the three functions represents a different type of interval, onwards referred to as short, intermediate and long intervals. Short and intermediate intervals are thought to reflect sensor errors or feeding interruptions, such as when cows step out of the feeder to chew, look around, or successfully defend against displacement (short intervals), or drink or feed at another location (intermediate intervals). Long intervals would represent between-meal behaviours, such as sleeping, social interactions or ruminating. Therefore, the higher intersection between the different functions, separating intermediate and long visits, is used as the meal criterion: ±20–30 min. This criterion can either be applied to all intervals or only to those intervals during which no pen mates visited the feeder, which avoids overestimation of feeder occupation time due to duplicate occupation and may preserve information on feeder competition (Maselyne et al., 2016).

In dairy cows, the method has been tested (Howie et al., 2009; Tolkamp et al., 2012, 2011, 1998; Tolkamp and Kyriazakis, 1999; Yeates et al., 2001) and applied (e.g. Azizi et al., 2009; DeVries et al., 2003; Kok et al., 2017). In other species, tests were also successful, including dolphin calves (Tolkamp et al., 2011), broilers (Howie et al., 2010, 2009; Tolkamp et al., 2012), turkeys and ducks (Howie et al., 2010; Tolkamp et al., 2012), and individually-housed rats (Tolkamp et al., 2011). In pigs, however, the method was only effective on night-time visits (Tolkamp et al., 2011). It was theorised that day-time visits were too heavily influenced by feeder competition for proper interval modelling. The role of feeder competition and the biological relevance of different types of visit intervals were, however, never tested empirically.

This study aimed to enhance our understanding of visit intervals in *ad libitum*-fed growing-finishing pigs through behavioural observations, with the ultimate aim of supporting the determination of an appropriate meal criterion and application method (i.e. always or only when no pen mates visited the EFS during the interval). Our aims were to 1) test the method that classifies interval types using a three-part probability density function; 2) determine whether feeder competition differs between identified interval types and application methods; and 3) describe and compare pig behaviours during and between the interval types.

2. Methods

This observational study was performed on commercially-reared growing-finishing pigs, complying with relevant EU and German guidelines and regulations. As no invasive or harmful procedures were applied, ethical approval for animal experimentation was not required. All data processing and analyses were performed in R, version 4.2.3 (R Core Team, 2023), and the significance level was set at $P < 0.05$. Results are reported as mean ± standard error of the mean.

2.1. Animals and housing

This study included 110 tail-docked growing-finishing barrows (Landrace x Large White), reared between September and December 2021 at a Topigs Norsvin (pig breeding company, the Netherlands) growing-finishing farm in Germany. Pigs were housed in ten pens across five rooms (n=11 pigs/pen). Each room was mechanically ventilated and contained four pens, of which two were included in this study. Each pen was equipped with an IVOG® EFS (Hokofarm group, the Netherlands), from which pelleted feed was provided *ad libitum* (until d33 post arrival, Select Delta 2: 16.2% crude protein (CP) and 13.2 MJ/kg metabolisable energy (ME); between d33–64, Select Delta 4: 15.3% CP and 13.1 MJ/kg ME; post d64, Select Delta 5: 13.8% crude protein an 13.0 MJ/kg ME (feed was mixed for 2–3d upon every switch); all

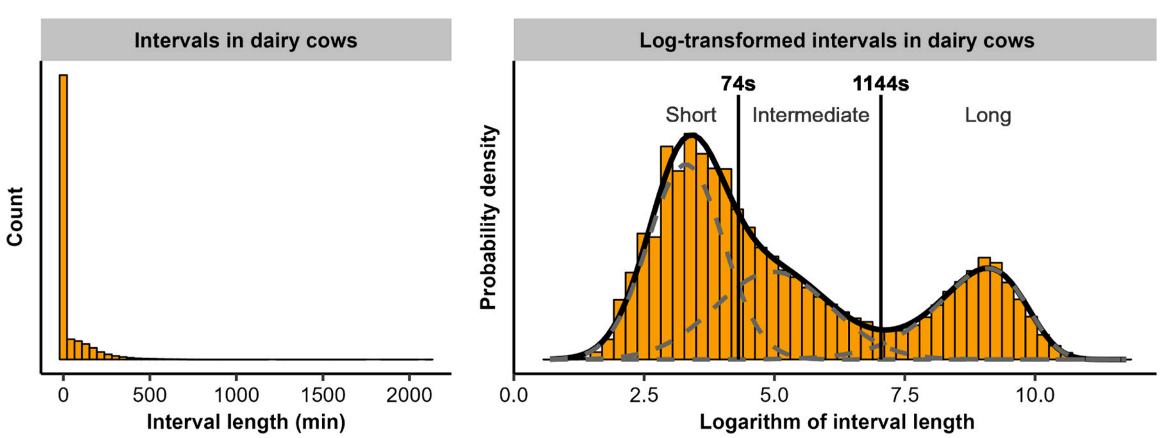

Fig. 1. An explanation of the meal criterion determination as developed by Tolkamp and Kyriazakis (1999), Tolkamp et al. (2000) and Yeates et al. (2001), using roughage feeding data of dairy cows from Kok et al. (2017). Histograms reflect the raw and log-transformed (natural logarithm) visit intervals. For the log-transformed intervals, the best fitted probability density function (thick black line) and its three sub-functions (dashed grey lines, two Gaussians and a Weibull) are shown. The three sub-functions are thought to represent different types of visit intervals, which can be quantitatively differentiated from each other using the intersections between the functions - i.e. the possible meal criteria (black vertical lines, quantified in seconds). Short, Intermediate and Long intervals are defined as interval lengths below, between and above these intersections, respectively.

produced by Royal Agrifirm Group, the Netherlands). IVOG® EFS are single-spaced feeders that continuously have feed available in the trough (a picture is provided in Supplementary Figure S1). To feed, a pig enters its head into the EFS, which blocks its field of vision outside the EFS and protects the head from manipulation by pen mates, but beyond the head/neck the pig is unprotected. A metal bar on the floor prevents pigs from lying down with their heads in the EFS Supplementary Figure S1. Besides the EFS, each pen was equipped with a crude fibre station that provided chopped straw when pigs interacted with a chain, two drinking nipples for *ad libitum* water, fully slatted floors, and putative environmental enrichment in the form of a hanging wooden block, chains with plastic rings and hanging ropes or hosepipes (enrichment differed between pens and across time). A schematic overview of the pen is given in Supplementary Figure S1. No lights were on during the day, but windows provided natural lighting. At night, a weak light provided enough visibility for behavioural observations from camera. All management procedures were determined and performed by Topigs Norsvin employees. The animal caretaker checked the pigs twice daily. Pigs arrived at (mean±standard error) 24.7±0.4 kg and grew to 106.1±0.9 kg in 76d. They were slaughtered in three batches with only the heaviest pigs slaughtered in each batch (first batch after 83d). In addition, two pigs from two pens were removed from the trial before behavioural data was collected, due to health issues.

2.2. Data collection

2.2.1. Classification of interval types and calculation of possible meal criteria

The IVOG® EFSs recorded the feeder visits of each pig. An RFID antenna and a load cell underneath the trough identified the feeding pig and the quantity of feed consumed per visit, respectively. The start and end time of each visit were registered, from which the interval between successive visits of an individual pig could be calculated (i.e. the difference between the end of one visit and the start of the next, in seconds). As EFS data can contain mistakes, data were cleaned using the same steps as described in Section 1 of the Supplementary Methods of Bus et al. (2023). This led to the manipulation of 6.4% of EFS visits, of which approximately half were fully removed and half had only feed intake removed; more details are provided in Supplementary Table S1.

After cleaning, all visit intervals of the growing-finishing phase were used to calculate thresholds beneath which intervals would be considered short and intermediate, i.e. the putative meal criteria. As described in the introduction, this was done by fitting a three-part probability density function on the log-transformed visit intervals. A small value (1.1 s) was added to allow transformation of intervals of 0 s, and a natural logarithm was used. The probability density function consisted of two Gaussian and one Weibull functions (based on Tolkamp et al., 2000; Tolkamp and Kyriazakis, 1999; Yeates et al., 2001), and was fitted using the *fitdist()* function of the *fitdistrplus* package (Delignette-Muller and Dutang, 2015). The exact probability density function is given in Eq. 1.

$$p\cdot\frac{1}{\sigma_1\cdot\sqrt{2\pi}}\cdot\exp\left(\frac{-(\ln(x)-\mu_1)^2}{2\sigma_1^2}\right)+q\cdot\frac{1}{\sigma_2\cdot\sqrt{2\pi}}\cdot\exp\left(\frac{-(\ln(x)-\mu_2)^2}{2\sigma_2^2}\right)+(1-p-q)\cdot\frac{c\cdot\ln(x)^{c-1}\cdot\exp(-\left(\frac{\ln(x)}{a}\right)^c}{a^c} \quad (1)$$

In which: x as the visit intervals, p and q as the proportions of intervals assigned to the first and second Gaussian functions, respectively, μ_1, μ_2, σ_1 and σ_2 as the mean and standard deviations of the first and second Gaussian functions, and a and c as the scale and shape parameters of the Weibull function, respectively (Maselyne et al., 2015). After fitting, possible meal criteria were calculated as the intersections of the first two (hereafter referred to as 'lower criterion') and the latter two (hereafter referred to as 'upper criterion') function parts using the *uniroot()* function of the *stats* package (R Core Team, 2023), and these were backtransformed.

2.2.2. Behavioural observations

Behavioural observations were performed from video recordings, obtained using two Lorex 4 K Ultra HD Smart Deterrence (8MP) cameras (Lorex Corporation, Canada) installed on the wall of the pen at a height of approximately 2 m. For each pig (n=108), in the middle of the growing-finishing phase (d54 post arrival) a short (i.e. < lower criterion) and an intermediate (i.e. ≥ lower criterion & < upper criterion) visit interval were randomly selected for observation. If an animal caretaker was seen on the video footage during an observation, the interval was resampled. Behavioural observations were performed from the moment a pig exited the EFS until it re-entered the EFS, with exit and entrance defined as the full head having crossed the outer fence of the EFS (see Supplementary Figure S1).

Behavioural observations were performed on the focal pig, partly using continuous observations and partly using instantaneous scan sampling, with the software BORIS (Friard and Gamba, 2016). Short intervals were observed continuously from feeder exit until feeder re-entrance, where re-entrance was always earlier than the lower criterion. Intermediate intervals were initially scored continuously, until the lower criterion was reached, and beyond that 15 s-instantaneous scan sampling was performed until the end of the intermediate interval. Observed behaviours indicated exiting the feeder (either leaving or being displaced, only for continuous observations), ingestive behaviour (feeding from the EFS, drinking or feeding crude fibre), exploration of the pen, social interactions (social nosing, aggression, displacing a pen mate from the EFS or in the pen, tail or ear manipulation, belly nosing and mounting), and other activities (queuing, upright inactive, lying inactive, locomotion, and other behaviour while upright or lying) - the full ethogram is provided in Supplementary Table S2. If a pig was not well visible, this was scored as 'out of view' and deducted from the observed time.

Behavioural data were expressed as the proportion of visible time or scans upon which a behaviour was performed. Behaviours that were shown in both short and intermediate intervals by less than 10% of the pigs and for an average duration of less than 10% of observed time or scans were not analysed due to low occurrence. This included feeding concentrates or crude fibre, queuing for the EFS, ear and tail manipulation, belly nosing, aggressive and non-aggressive displacements in the pen (successful or unsuccessful, receiving or initiating), mounting, upright inactivity, and lying other. In addition, for displacements from the EFS, both receiving and initiating, aggressive and non-aggressive displacements were merged.

2.3. Data analysis

2.3.1. Interval selection

Visualisations were used to check how representative the selected intervals were of the full dataset, comparing the selected short and intermediate intervals to the full dataset. Histograms were made of their hourly distributions and interval lengths.

2.3.2. Feeder competition

2.3.2.1. Displacements from the feeder. The number of intervals scored as 'leaving the EFS' or 'being displaced from the EFS' were compared for the short and intermediate intervals using a generalised linear mixed model with a binomial family distribution. The interval type was included as a fixed factor, and pig and pen were included as random factors. A χ^2-test was used to determine whether the interval type had a significant association with the manner of exiting the EFS.

Additionally, for each interval the latency until a pen mate entered the EFS was calculated as the time difference between the exit time of the observed pig and the entrance time of the first following visiting pig. If the following pig was the same as the observed pig, no latency was recorded. To compare the latencies between intervals initiated by displacement or leaving, a generalised linear mixed model with a binomial family distribution was fitted with the manner of exiting as the response variable, the latency to first entrance of a pen mate as a fixed factor, and pig and pen as random factors. A χ^2-test was used to determine whether the latency had a significant association with the manner of exiting the EFS.

2.3.2.2. Feeder visits by pen mates during the interval. For each observed interval, it was extracted how many pen mates had visited the EFS during the interval. If a pen mate visited multiple times, each visit was counted as a separate occurrence. The distribution of the number of visits made by pen mates during an interval was visualised using a histogram and with a scatter plot as a function of interval length.

Subsequently, intervals with different numbers of pen mate visits were compared for short intervals only, as for intermediate intervals the number of visiting pen mates was seen to be a function of interval length. Short intervals were sorted into two groups: intervals during which 1) no pen mates entered the EFS; or 2) at least one pen mate entered the EFS. For each behaviour, groups were compared on the proportion of pigs that performed a behaviour and the proportion of time spent on a behaviour. In later analyses, a third variable was also included: the proportion of time spent on a behaviour if the behaviour was shown (see Section 2.3.3.2 '*Describing and comparing interval types*'). This was, however, not possible here due to too small sample sizes for several behaviours (drinking, exploring pen & lying). The analyses were performed using generalised linear mixed models with the behavioural variable as the response, the group (i.e. how many pen mates had visited the EFS) as a fixed factor, and pig and pen as random factors. A binomial family distribution was used to fit the proportion of pigs that performed a behaviour, and a beta family distribution with a logit link for the proportion of time spent on a behaviour. A χ^2-test was used to determine whether the behavioural variable differed between interval groups.

2.3.3. Behaviour during the intervals

2.3.3.1. Describing behavioural sequences within intervals. From the behavioural observations, it was extracted how many pigs displayed a behaviour at each time point. For the short and the first part of the intermediate intervals (i.e. the continuous observations), this was done for every second, and for the second part of the intermediate intervals (i.e. the instantaneous observations), for every scan (i.e. 15 s). Subsequently, an area plot was used to visualise the number of pigs displaying each behaviour across the intervals, split for the interval (i.e. short, moderate) and observation (i.e. continuous, instantaneous) type.

2.3.3.2. Describing and comparing interval types. A comparison of the interval types is inherently biased, because the observed time differs depending on the interval type; any duration between 1 s to the lower criterion for short intervals and from the lower to the upper criterion for intermediate intervals. This bias cannot be circumvented, but to mediate it we report all behavioural results using three variables: the proportion of pigs performing a behaviour, the proportion of time spent on a behaviour, and the proportion of time spent on a behaviour only for the intervals in which the behaviour was shown (i.e. all proportions of time equal to zero were removed). For each behaviour, these variables were compared statistically beneath the lower criterion (i.e. short versus intermediate intervals, using the continuous observations) but not beyond the lower criterion (i.e. for intermediate intervals) as we did not want to compare proportion of duration with proportion of scans. We used generalised linear mixed models with the behavioural variable as response, interval type as a fixed factor and pig and pen as random factors. For the proportion of pigs performing the behaviour, a binomial family distribution was applied, and for the proportion of time spent, whether the behaviour occurred or not, a beta family distribution with a logit link was used. A χ^2-test was used to determine whether the behavioural variable differed between (the first parts of) the interval types.

3. Results

3.1. Classification of interval types and calculation of possible meal criteria

Fig. 2 shows that the distribution of visit intervals is heavily right-tailed, with the majority of interval lengths in the range of seconds. The fit of the three-part probability density function is not optimal, with especially the centre (i.e. the second part of the function) not fully following the data. The identified possible meal criteria were at 60 and 1672 s, or 1 and 28 min.

3.2. Quality of selected intervals for behavioural observations

From the 108 pigs, a short interval could be selected on d54 for 101 pigs and an intermediate interval for 104 pigs. Fig. 3 shows the distribution of these selected intervals across the different hours of the day as well as the distribution of the interval lengths. Most intervals were selected during the peak hours in pig feeding activity but intervals were also selected at lower occupation moments, giving a good representation of the diurnal distribution in visit intervals. For interval length, there was a larger representation of short intervals between approximately 10–25 s and of intermediate intervals between 1–2 min. For both interval types, this was also seen in the full dataset but to a smaller extent. This suggests a slight overrepresentation of relatively short-lasting short and intermediate intervals (raw data not shown).

3.3. Feeder competition

Feeder competition was firstly compared between interval types, using displacements from the EFS, and secondly between application methods of meal criteria, by testing whether intervals differ depending on whether pen mates visited the EFS during the interval or not.

3.3.1. Displacements from the feeder

Most visit intervals were initiated by pigs exiting the EFS without interference of another pig (76% of intervals), rather than displacements (24% of intervals) (Fig. 4). Intermediate intervals were more often initiated by displacements (35% of intervals) than short intervals (13% of intervals, $\chi^2 = 12$, $P < 0.001$). If a pen mate entered the EFS within the interval, intervals initiated by a displacement (n=44 intervals) had a lower latency for the pen mate to enter the EFS than intervals not initiated by a displacement ($n = 57$, $\chi^2 = 6.24$, $P = 0.012$). Indeed, for intervals initiated by displacements, in 93.2% of intervals a pen mate had entered the EFS within 1 s after the interval began, while for intervals not initiated by displacements the latencies were more spread out, with only 43.9% of latencies being 1 s or less (Fig. 4).

3.3.2. Comparing intervals with or without feeder occupation by pen mates during interval

The number of visits performed by a pen mate during a pig's interval ranged from 0 to 18, with those during short intervals never exceeding 3 (Fig. 5). The number of pen mates visiting increased as a function of the interval duration. During 80% of short intervals, no pen mate visited the EFS, compared to 20% of intermediate intervals. In contrast, 16% of short intervals and 21% of intermediate intervals had one pen mate visiting the EFS during the interval, and 4% of short intervals and 60% of intermediate intervals had more than one pen mate visiting the EFS.

Fig. 6 (left pane) shows the proportion of pigs performing a

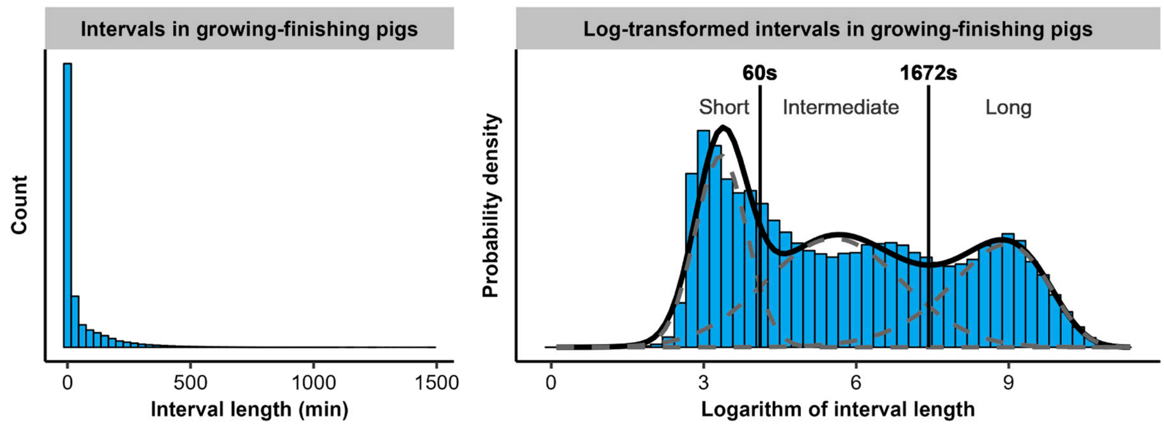

Fig. 2. Histograms of the raw or log-transformed (natural logarithm) visit intervals of the growing-finishing pigs. On the transformed intervals, the probability density function is added (thick black line). It consists of three parts that separate the different types of visit intervals (short, intermediate and long, grey dashed line), with the possible meal criteria on their intersections.

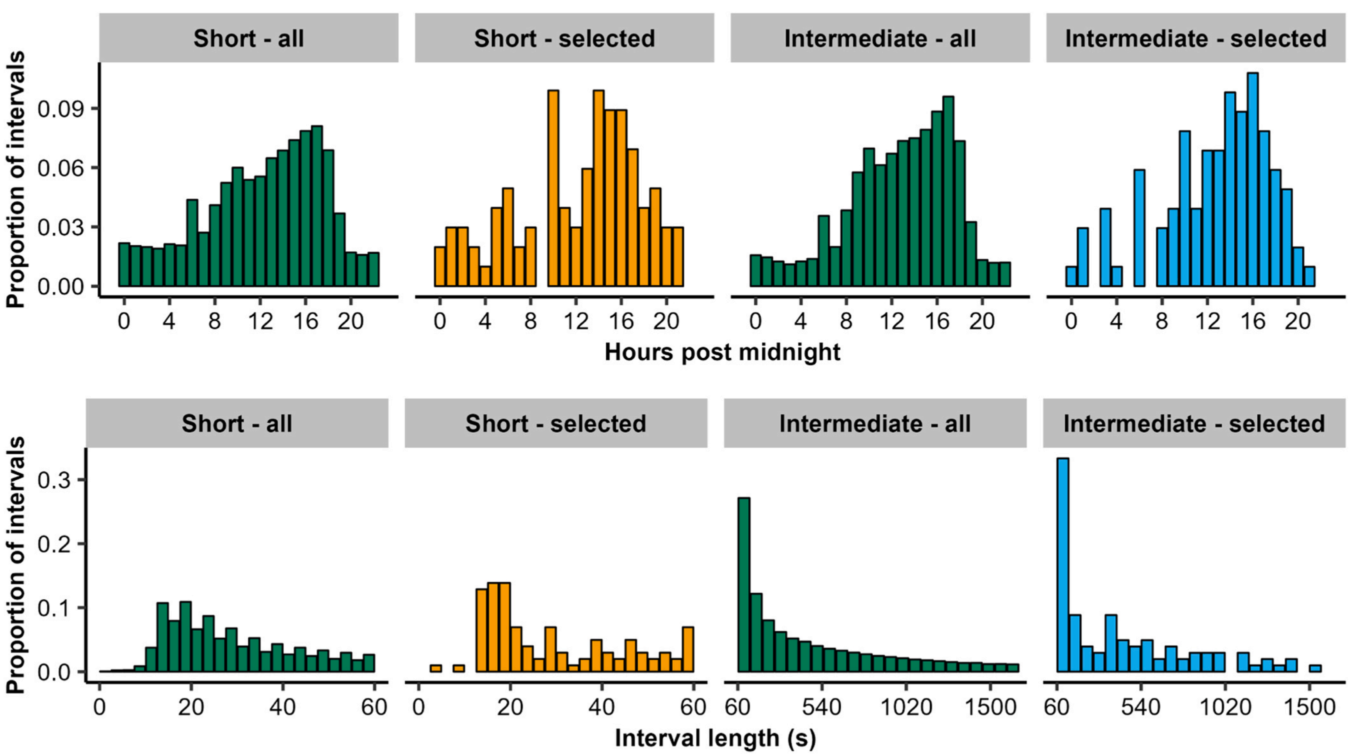

Fig. 3. The distribution of all and selected short (≤60 s) and intermediate (>60 s and ≤1672 s) visit intervals across the hours of the observation day (top four panels), and the distribution of the length of these intervals (bottom four panels). 'All' intervals were from the entire growing-finishing phase, while 'selected' intervals were those intervals from d54 on which behavioural observations were performed.

behaviour depending on whether at least one pen mate visited the EFS during the short interval. Aggression was shown by fewer pigs ($\chi^2 = 28.91$, P < 0.001) and during a smaller proportion of time ($\chi^2 = 7.57$, P = 0.006) if no pen mates visited the EFS during the interval, while pen exploration was shown for a larger proportion of time ($\chi^2 = 4.68$, P = 0.030). There were no other differences in the proportion of pigs performing or the proportion of time spent on other behaviours between intervals with or without pen mate visits.

3.4. Behaviour during the intervals

Behaviour during the visit intervals, after EFS exit, is reported firstly by describing behavioural sequences as the interval progresses, and secondly by comparing the behaviours shown during different interval types.

3.4.1. Describing behavioural sequences within intervals

A descriptive overview of the behaviours performed from the start until the end of the interval for each interval type is provided in Fig. 7. Intervals began with pigs leaving the EFS, either through displacement or without intervention of another pig (0–3 s), after which pen exploration, locomotion, upright other, social nosing and aggression mainly occurred (3–9 s). Subsequently, drinking and lying inactive became more common (9–60 s), and from about 3 min after the start of the interval onwards lying inactive was the most occurring behaviour. This pattern seemed similar for the short and intermediate intervals, however for intermediate intervals the area of performing aggression immediately after exiting the EFS appeared larger than for short intervals, as did

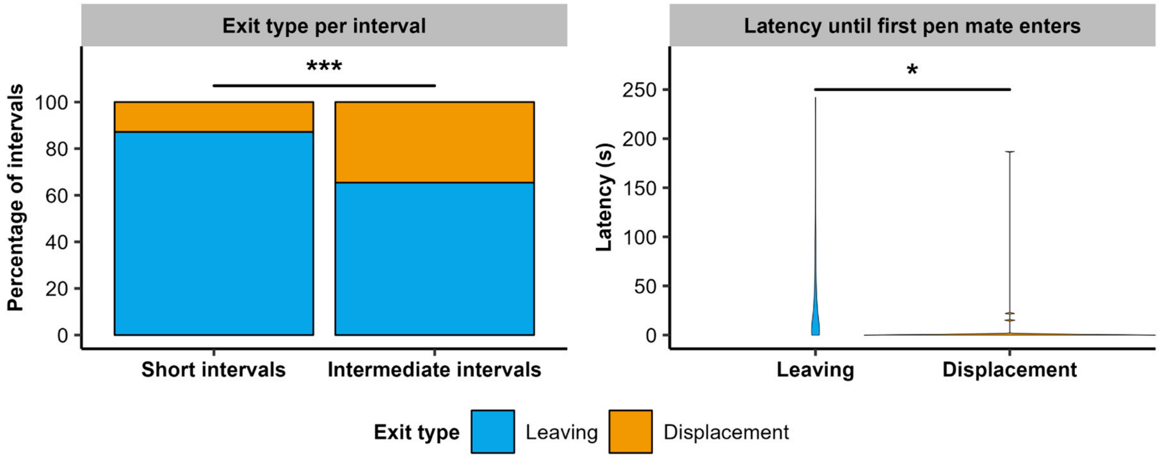

Fig. 4. On the left, the percentage of visit intervals initiated by displacement or 'leaving' (i.e. without physical contact of another pig) for short and intermediate intervals. On the right, a violin plot of the latencies until a first pen mate enters the feeder within an interval, for intervals initiated by displacement or leaving. Significant differences are shown with stars (*: P<0.05; ***: P<0.001).

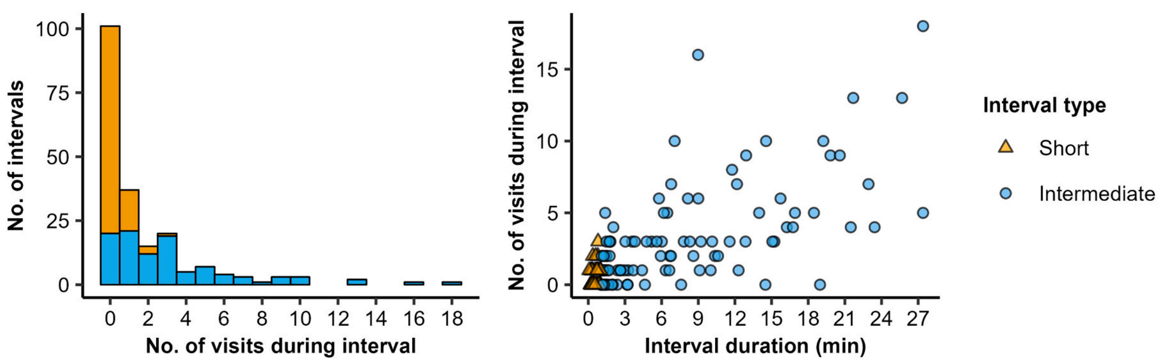

Fig. 5. On the left, the number (No.) of visits by pen mates that occurred during short and intermediate intervals of observed pigs. On the right, the number of visits by pen mates plotted against the interval duration, per interval type.

the area for lying inactive throughout the interval duration.

3.4.2. Describing and comparing interval types

Fig. 8 shows the proportion of pigs and time (in duration or number of scans, both for all intervals and only for intervals in which the behaviour was performed) performing a behaviour in the short and intermediate intervals. All behaviours except upright other were shown by more pigs in the first 60 s of the intermediate than the short intervals (pen exploration: χ^2 = 4.17, P = 0.041; locomotion: χ^2 = 6.99, P = 0.008; social nosing: χ^2 = 20.96, P < 0.001; performing aggression: χ^2 = 9.86, P = 0.002; drinking: χ^2 = 18.21, P < 0.001; lying inactive: χ^2 = 26.86, P < 0.001). For upright other, there was a tendency for more pigs performing this behaviour in the first 60 s of the intermediate than the short intervals (χ^2 = 3.15, P = 0.076). The proportion of time spent on a behaviour concerning only the intervals during which a behaviour was performed was higher during the first 60 s of the short intervals for pen exploration (χ^2 = 8.17, P = 0.004), locomotion (χ^2 = 7.45, P = 0.006), upright other (χ^2 = 5.37, P = 0.020), social nosing (χ^2 = 6.70, P = 0.010) and performing aggression (χ^2 = 27.07, P < 0.001), while no difference was seen for drinking (χ^2 = 0.72, P = 0.396) and lying inactive (χ^2 = 2.58, P = 0.108). When taking all the intervals, the proportion of time was higher for drinking (χ^2 = 9.70, P = 0.002) and social nosing (χ^2 = 7.14, P = 0.008) during the first 60 s of intermediate than short intervals, but not for any of the other behaviours (pen exploration: χ^2 = 0.09, P = 0.766; locomotion: χ^2 = 0.62, P = 0.432; upright other: χ^2 = 0.05, P = 0.830; performing aggression: χ^2 = 0.23, P = 0.635; lying inactive: χ^2 = 1.47, P = 0.226). Beyond the first 60 s of the intermediate intervals, the behaviours shown by most pigs were pen exploration, social nosing and lying inactive, where most of the interval duration was spent on lying inactive followed by pen exploration - both when intervals during which a behaviour did not occur were included and when not.

4. Discussion

This study aimed to enhance our understanding of visit intervals in *ad libitum*-fed growing-finishing pigs through behavioural observations, with the ultimate aim of supporting the determination of an appropriate meal criterion and application method (i.e. always applying the criterion or only when no pen mates visited the EFS during the interval). We tested the fit of the meal criteria calculation method that classifies interval types using a three-part probability density function (two Gaussians and a Weibull, i.e. the method of Tolkamp and Kyriazakis 1999, Tolkamp et al. 2000 and Yeates et al. 2001). Subsequently, we determined whether feeder competition differed between identified interval types and application methods, and described and compared the behaviours of pigs as the interval progresses and during the interval types.

4.1. Classification of interval types and calculation of possible meal criteria

Although the distributions of the raw feeding visit intervals strongly resembled those seen in dairy cows (i.e. compare the left panels of Figs. 1

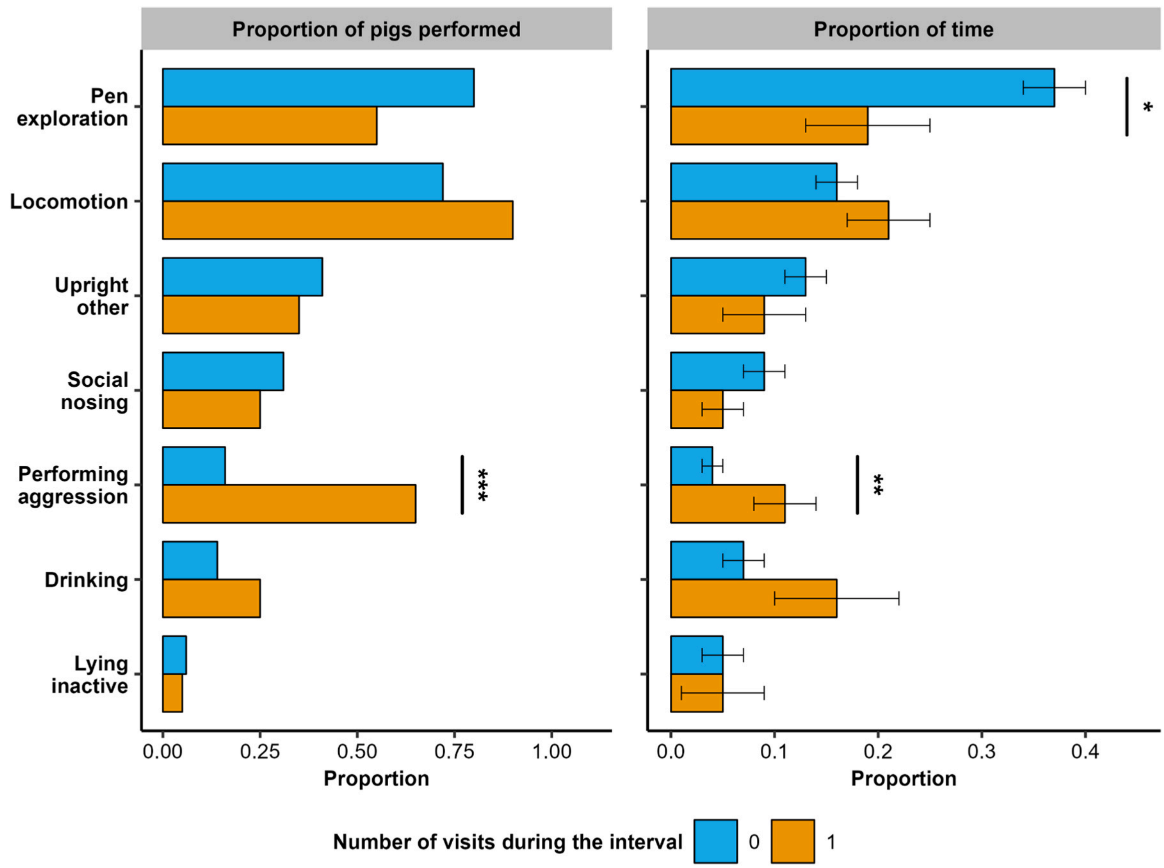

Fig. 6. The proportion of pigs performing (left) and proportion of time spent on (right) a behaviour in an interval during which no or at least one pen mate visited the feeding station. Significant differences between interval types are shown with stars (*: P<0.05; **: P<0.01; ***: P<0.001).

and 2), after log-transformation the distributions appeared only partially similar. Both distributions included three separate curves, but the second curve (i.e. intermediate intervals) contained a much larger share of the data in pigs than in dairy cows, mostly at the cost of the first curve (i.e. short intervals). Compared to other studied species (dolphin calves, broilers, ducks and individually-housed rats), distributions in *ad libitum*-fed pigs also appeared similar before transformation, but after log-transformation distributions of other species were seen to be even more different from the pigs' than the dairy cows'. Additionally, this larger proportion of intermediate intervals was not seen for any of them (Howie et al., 2010, 2009; Tolkamp et al., 2011). The probability density function obtained a good fit in all these species, however, in pigs the fit was considerably poorer. Nevertheless, the identified possible meal criteria were in similar ranges, namely around one (short-intermediate) and twenty to thirty (intermediate-long) minutes (e.g. Azizi et al., 2009; Kok et al., 2017; Tolkamp et al., 2012). In pigs, both meal criteria may have been underestimated due to the poor fit, as visually the intersections of the curves seem to not correctly separate the three different curves. Possibly, in pigs it may be better to identify the meal criteria by determining the two minima in a probability density curve for which no underlying distribution is assumed. Although this might be less precise, it would still be more objective than alternative methods that apply visual determination of a breakpoint in a distribution. In this study, finding the minima would result in a lower criterion of approximately 1.6 min and a higher one of approximately 28.4 min. Another alternative is to abandon statistical calculation of meal criteria and use the occurrence of non-feeding-related behaviours, like social nosing or lying inactive, to separate meals instead. However, this requires behavioural observations and can therefore not feasibly be applied on large datasets from EFSs.

4.2. Feeder competition

For both short and intermediate intervals, EFS exit was most commonly not physically induced by a pen mate, though physical displacement from the EFS more often initiated intermediate than short intervals. Intervals initiated by displacements were almost always immediately succeeded by a pen mate visiting the EFS, while after leaving without displacement the latency for a pen mate to enter the EFS was longer. If a pen mate entered the EFS during the interval, aggression was shown by more pigs and also for a larger proportion of time. This aggression was likely competition-related, as aggression was mostly shown immediately after EFS exit (Fig. 7) and only little beyond the first 60 s of the intermediate interval (Fig. 8). These findings suggest that successful feeder competition, during which a pig is successfully displaced from the EFS, is more associated with intermediate than short intervals. This competition effect may explain the larger contribution of intermediate intervals to the interval distribution of pigs than dairy cows (Figs. 1 and 2), because competition effects are likely larger in pigs, which share one single-spaced feeder, than in dairy cows, which in these automated-sensor systems generally have their own roughage bin or share it with one other cow. Interestingly, though, when comparing interval types we found that even though more pigs performed aggression in intermediate intervals than in short intervals (Fig. 8), the proportion of time spent on aggression was larger in short than intermediate intervals. This could imply that displacements were also attempted in short intervals, but that these were less successful than in intermediate intervals. In other words, it seems that aggression in short intervals is associated with successful defence from displacement, allowing the feeding pig to quickly re-enter the EFS and continue its meal, while aggression in intermediate intervals more often led to successful displacement and thus interruption of feeding.

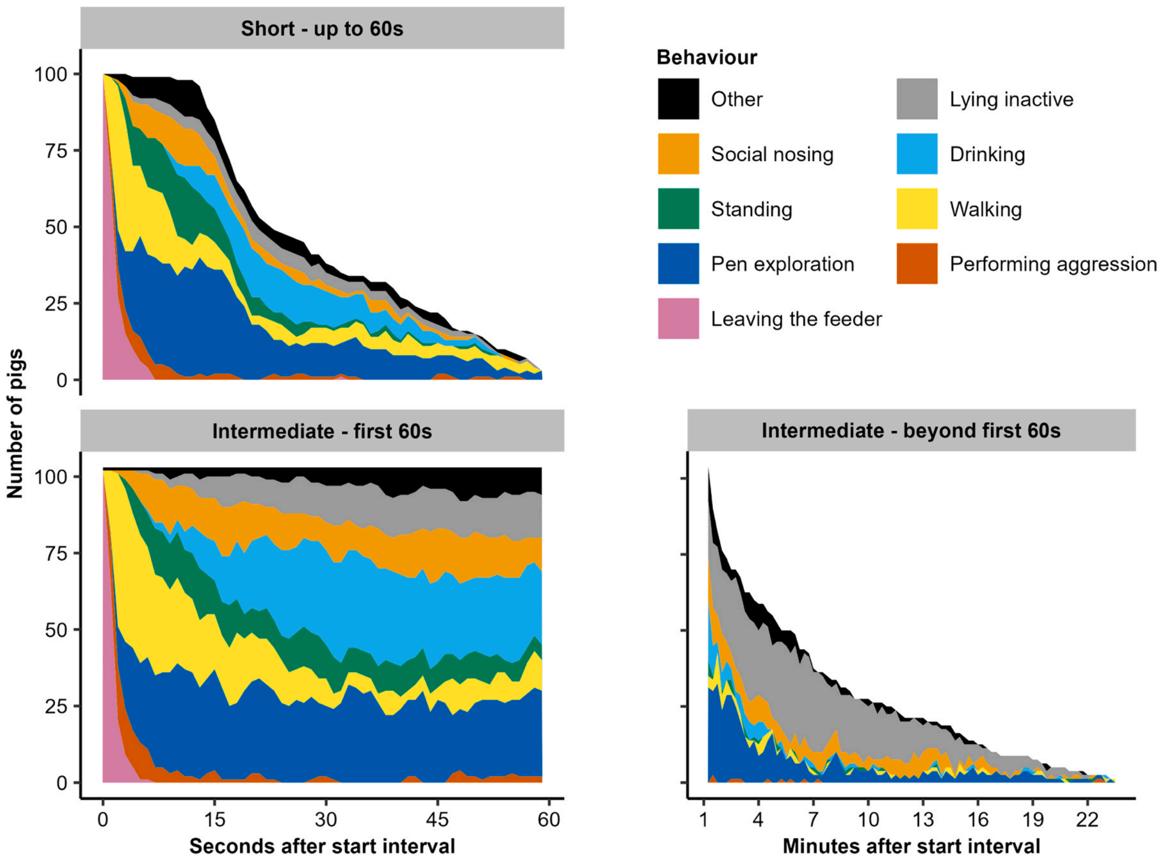

Fig. 7. The number of pigs performing each behaviour from the beginning to the end of the short and intermediate intervals. The top left panel gives the number of pigs performing a behaviour during every second of the short intervals (up to 60 s maximum duration), and the bottom left panel gives the same for the first 60 s of the intermediate intervals. On the bottom right, the number of pigs performing a behaviour at every scan is given until the end of the intermediate intervals, i.e. every 15 s beyond the first 60 s of the interval. As observation ended when the focal pig re-entered the electronic feeding station, the number of pigs included in the plot decreases as the interval length increases.

4.3. Behaviours during the intervals

We theorised that short intervals may be partially explained by EFS error, for example through temporary loss of contact with the RFID tag of the pig, but this was not seen to be an issue in this study. There were only two occurrences of a pig observed to be in the EFS (i.e. behaviour 'feeding concentrates' in Supplementary Table S2) while the EFS data defined that time point as a visit interval (results not shown). This could but does not necessarily represent EFS failure, as it is not known how far inside the EFS the pig's head must be for the RFID system to detect its ear tag and, consequently, how well our definition of 'inside the EFS' corresponds with the detection range of the EFS. In either case, a significant contribution of EFS error to any type of interval seems unlikely at this low occurrence.

The behavioural sequences shown during the intervals were fairly similar between short and intermediate intervals. Nevertheless, a few differences could be seen. First, more pigs showed aggression after EFS exit in intermediate intervals, as discussed previously. Second, lying inactive was much more prominent in later stages of the intermediate intervals than at any stage of the short intervals. This corresponds with the larger proportion of pigs lying inactively during the intermediate compared to the short intervals, especially beyond the first 60 s of the intermediate intervals (no statistical comparison possible). As growing-finishing pigs in conventional housing systems spend more than 60% of their days lying inactively (Guy et al., 2002; Maselyne et al., 2014), we expected that intermediate intervals, which could last up to 28 min, would contain lying inactive behaviour. Our results additionally demonstrated that lying inactive was already prominent early in the intermediate intervals, reaching its highest levels within 2 min of EFS exit.

Despite the similar-looking sequences, quantitative differences in all behaviours could be identified between the interval types. All behaviours except upright other were shown by more pigs in the first 60 s of the intermediate intervals than in the short intervals. For most behaviours, this is unlikely to be biologically relevant but rather represents a statistical artefact. In intermediate intervals, which were always at least 60 s, more behaviours could be shown than in the short intervals, which were always shorter than 60 s. Nevertheless, for social nosing and drinking these differences were very large (30–40% of pigs difference), suggesting that other factors may also be at play. Indeed, besides by more pigs also more time was spent on social nosing and drinking during the first 60 s of the intermediate intervals. In addition, more time was spent on pen exploration, locomotion, upright other and social nosing in short intervals if the behaviour was shown.

The proportion of time spent on a behaviour may also be overestimated in short compared to intermediate intervals, due to the shorter total time. Nevertheless, the duration difference for upright other was more than 10% longer in short intervals, moved in the same direction for intervals during which it was and was not performed, and was the only behaviour for which there were not more pigs that performed the behaviour in intermediate than short intervals. Together, these results suggest that upright other was more associated with short than intermediate intervals. It could be that part of the short intervals represented vigilance, where pigs stepped out of the EFS to see their surroundings - with the head inside the EFS their vision outside the EFS was blocked. In addition, while performing the observations we saw that pigs would

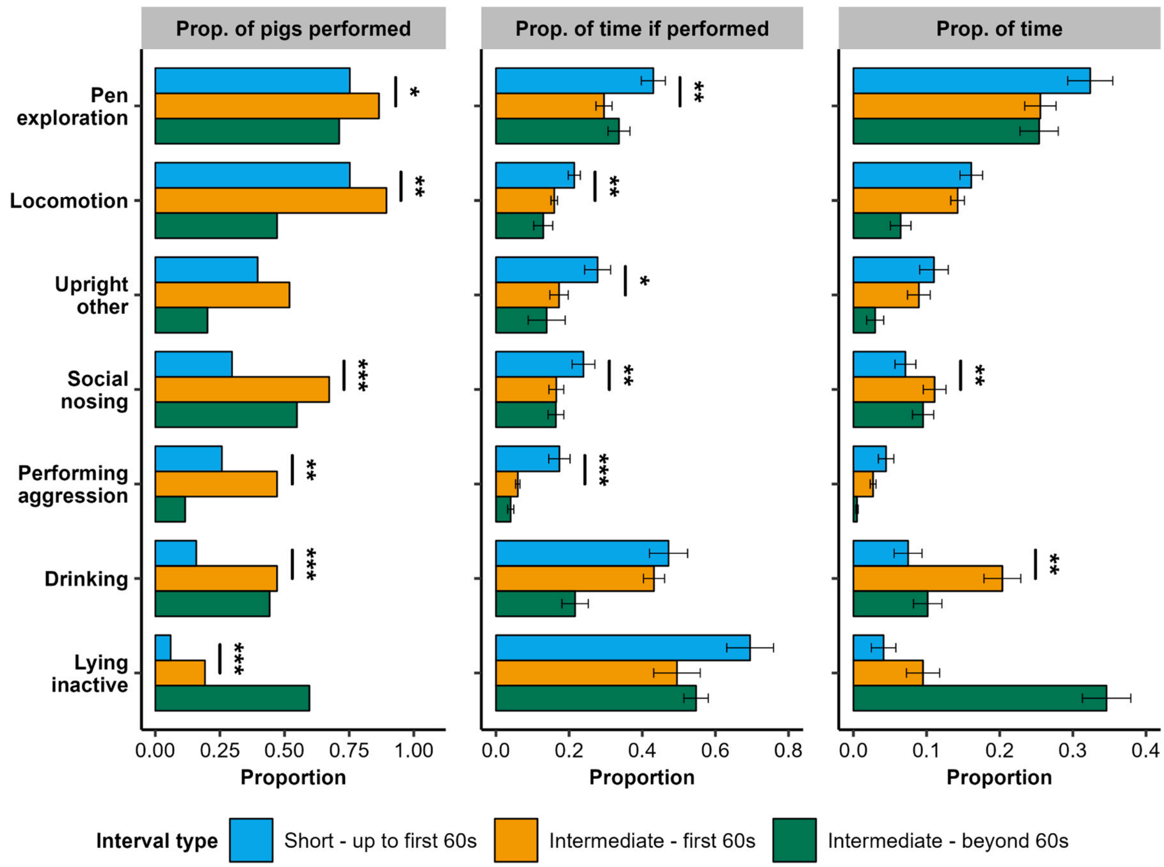

Fig. 8. For the first 60 s of short (blue) and intermediate (yellow) intervals, and the remaining time of the intermediate intervals (green), the proportion (Prop.) of pigs that performed a behaviour and the proportion of time spent on this behaviour either including or excluding ('if performed') occurrences of 0 s (means and standard errors). Proportion of time reflects the proportion of duration (blue & yellow) or the proportion of scans (green). Significant differences between the proportion of pigs and time on a certain behaviour for the first 60 s of the intervals are indicated with stars (*: $P < 0.05$; **: $P < 0.01$; ***: $P < 0.001$).

often back out of the EFS to stand outside and chew, before re-entering for the next bite. Although this could not be formally scored with our video quality and angles, we suggest that upright other in short intervals may reflect pigs that were chewing with their head out of the EFS. In addition, we saw that pen exploration, especially in short intervals, commonly represented nosing the floor near the EFS. This may have represented an attempt at rooting behaviour or the consumption of spilled pellets from the floor.

The behaviours mostly associated with intermediate intervals, besides lying inactive, were drinking and social nosing. The higher proportion of pigs and time spent drinking in intermediate intervals was likely due to the time required for pigs to reach the drinker, as also seen by the later emergence of drinking compared to other behaviours in the sequence plots (Fig. 7). This result may hence be quite specific to the layout of our barn. Interestingly, though, drinking was mainly performed during the first 60 s of the interval and not later, suggesting that pigs preferred to drink after feeding, which relates to the known high correlations between feeding and drinking behaviour (Bigelow and Houpt, 1988; Maselyne et al., 2015). Social nosing was performed more often and during more time in the intermediate intervals. Within this study's settings (i.e. definition of the behaviour and conventional housing system), social nosing occupies a relatively high proportion of pigs' active time (around 15%, Guy et al., 2002; Maselyne et al., 2014) and is likely related to both social and exploratory behaviour (Camerlink and Turner, 2013). In dairy cows, social behaviour, as a non-feeding-related behaviour, is thought to be associated with long intervals (Tolkamp and Kyriazakis, 1999), but at least in pigs this behaviour can already be seen during the intermediate intervals.

4.4. Implications for determining a meal criterion

In dairy cows, the intersection between intermediate and long intervals is used as the meal criterion, meaning that all visits separated by short or intermediate intervals are merged into a meal. It is argued that the behaviours putatively associated with intermediate intervals - drinking and feeding from the concentrate feeder - should be considered part of feeding behaviour, while those putatively associated with long intervals - social interactions, ruminating and resting - should not (Tolkamp et al., 2011). These interpretations of the interval types appear not to extrapolate to pigs. Like in dairy cows, in pigs short intervals seem to be interruptions in feeding, mostly caused by exploration, walking out of the EFS to be vigilant or to chew, and successful defence against displacements. Therefore, short intervals are arguably part of feeding behaviour - and thus of a meal. Intermediate intervals, however, are, next to drinking, heavily composed of social nosing and lying inactive, both non-feeding-related behaviours. In addition, they were more frequently caused by successful displacement from the EFS, after which no direct re-entry into the EFS was possible. Therefore, it does not seem reasonable in pigs to merge EFS visits separated by intermediate intervals into meals. Instead, we suggest that the lower intersection should be chosen as an adequate meal criterion, which in this study was calculated at 60 s. However, as discussed before, an alternative method to identify the true separation point of the short and intermediate intervals might be required, as the fit of the probability density function was poor.

Besides the choice of the meal criterion, it must also be decided how this criterion is applied. If an interval is shorter than the criterion, it could be chosen to only merge its corresponding visits into a meal if no pen mates visited the EFS during this interval. In our study, we found that the number of pen mates visiting the EFS during the interval increased with interval length. When focusing on only the short intervals, we found no strong evidence that intervals during which pen mates did or did not visit the EFS behaviourally differed from each other. However, intervals during which pen mates entered the EFS were more associated to feeder competition than intervals during which no pen mates visited (more aggression, less pen exploration). The choice of the application method, therefore, seems dependent on the research question. On the one hand, if competition is of interest, it would be logical to only merge visits that were separated by short intervals and during which no pen mates entered the EFS. This would preserve competition effects in the data. On the other hand, if competition is not of interest, merging all visits separated by short intervals may provide a more biologically-relevant dataset in relation to 'being occupied with the idea of feeding' (Maselyne et al., 2015). The latter option does have the consequence of overestimating the EFS occupation rate, as the merging could lead to multiple pigs registered as feeding simultaneously.

It should be noted that the behavioural observations in this study were performed on one day of the growing-finishing phase, and hence at a specific age of the pigs. As both feeding (reviewed by Bus et al., 2021) and home pen (e.g. Presto et al., 2013; own experiences with raw data from Bus et al., 2024) behaviour of pigs change as pigs age, results cannot simply be extrapolated to other age categories. Nevertheless, the high similarity between the selected intervals and the intervals of the entire growing-finishing phase (Fig. 3) suggest that at least the types of intervals are well-represented. In addition, the pen lay-out and the type of EFS used may have influenced the structure of the interval distributions and the behaviour shown during these intervals, for example via the number of available feeding spaces or the distance to the drinking nipples. Therefore, decisions on the determination and use of the meal criterion should be adapted to the housing situation. Moreover, in our experience, even sub-setting the data or using datasets from other pig rounds in the same farm leads to different outcomes for meal criteria determination (results not shown). We therefore advise that all studies using feeding data of pigs report a description of meal criteria calculation and application, accompanied by visualisations of their interval distributions. As for many other species it is also unknown what the different interval types represents, this could also be beneficial for other animals than *ad libitum*-fed pigs. This fundamental knowledge may contribute to developing better algorithms for PLF systems in pig husbandry. Finally, there is currently no knowledge on the effects of meal criterion application on the feeding data structure of individual pigs, although pigs are known to display individual feeding strategies (Bus et al., 2023, 2024; Fernández et al., 2011) and may hence be differently affected by the same meal criterion. This warrants further study.

5. Conclusion

We conclude that *ad libitum*-fed growing-finishing pigs have a similar interval distribution as dairy cows, except with a higher contribution of intermediate intervals (interval duration, in this study, between 1 and 28 min). The determination of meal criteria using a three-part probability density function led to reasonable criteria of 60 and 1672 s (1 and 28 min). Nevertheless, the fit of the function was poor and it may hence be better to fit a probability density function with an undefined shape instead. Short intervals (<1 min) were related to interruptions in feeding, caused by successful defence from being displaced, stepping out of the EFS to chew or be vigilant, and pen exploration including attempted rooting and searching for spilled pellets on the floor. Intermediate intervals likely signalled an end to feeding, where pigs were more commonly successfully displaced from the EFS and mostly performed drinking, social nosing and lying inactive behaviours. We suggest that in growing-finishing pigs, only visits separated by short intervals should be merged into a meal, and not, like in dairy cows, also those separated by intermediate intervals. Whether visits separated by short intervals during which pen mates visited the EFS should be merged depends on whether competition effects are of interest in the study or not.

CRediT authorship contribution statement

Jacinta D. Bus: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Visualization, Writing – original draft. **Iris J.M.M. Boumans:** Conceptualization, Funding acquisition, Methodology, Project administration, Supervision, Writing – review & editing. **Laura E. Webb:** Conceptualization, Methodology, Supervision, Writing – review & editing. **Eddie A.M. Bokkers:** Conceptualization, Funding acquisition, Methodology, Project administration, Supervision, Writing – review & editing.

Declaration of Competing Interest

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

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.applanim.2024.106219.

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