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Calf Health, Feeding and Social Behaviours within Groups Fed on Automatic Milk Feeders

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Abstract: Automatic calf feeders (AMFs) that supply milk for pre-weaning calves require group housing. This observational study assessed calf growth, health, feeding patterns and social behaviours prior to, during and following weaning in groups on the AMF. Calves were recruited from a single UK dairy farm and placed into two groups on the AMF between 3 and5 weeks of age (n = 19 and 13). They were fed milk near-ad libitum until 8 weeks of age when they entered a 2-week step-down weaning period. Daily milk consumption and the numbers of successful and refusal visits were collected from the AMF, along with weekly weights and health checks. Calf behaviour around the AMF was monitored through video analysis, and activity was assessed using tri-axial accelerometers. On average, the calves consumed approximately 3 L of milk three times a day from the AMF, confirming that limiting calves to twice daily feeding will restrict their desired milk consumption. The ADLG pre-weaning was 0.74 kg/d (SD 0.41 kg), rising to 0.99 kg/d (SD 0.46 kg) over weaning and 1.05 kg/d (SD 0.12 kg) post weaning. Refusal visits to the AMF, social interactions, displacements and cross sucking all increased over the weaning periods, suggesting that the calves were experiencing frustration due to a lack of expected milk rewards rather than hunger as ADLG continued to increase. Female calves also had more successful and refusal visits to the AMF than males, along with higher displacement indexes (p = 0.052), suggesting single-sex groups may be beneficial to AMFs. Calf activity had a diurnal pattern, with the highest standing times being during mid-morning and early evening, which may put pressure on limited resources if all calves are active during these particular time periods.

Keywords: calves; automatic milk feeder; behaviour; health

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1. Introduction

The management of dairy calves conventionally involves separation from the dam within the first few days of life, followed by manual feeding of either whole milk or milk replacer until weaning [1]. In many countries, including the UK, calves are often housed in either individual or small group pens due to the perceived benefits for health management from reduced disease exposure and transmission found in larger groups [2,3]. However, limited social housing can lead to problems such as increased fearfulness of unfamiliar calves [4], increased fear in novel social situations [5] and neophobia [6] resulting in poor solid feed intakes [7].

Cattle are gregarious by nature, with calves prepared to work to achieve social contact with each other, preferring full body contact in comparison to head only contact [8]. The group housing of calves allows for the development of normal social responses [9] along with providing social support and social buffering [10], which can help decrease stress responses. Housing with others also enables social learning, with increased behavioural flexibility and cognitive performance [11,12], which is probably due to higher variability within the environment of group-housed compared to individually housed calves [13]. Lastly, group housing tends to increase space allowance per calf, which can enable active behaviours such as running and playing [14,15], which are indicative of good welfare [16]. There are some disadvantages of group compared to individual housing, with a perceived increased risk of disease spread and the occurrence of cross sucking reported to be more frequent in groups with high numbers of calves [17], which can lead to hair loss and inflammation of the sucked area [18].

The use of automatic calf feeders (AMFs) for the provision of milk feeding is increasing, with improved technology allowing for the automatic mixing of milk replacer powders, individualised feeding regimens and self-disinfecting teats. AMFs necessitate larger group sizes, typically of 10 to 15 calves or more per feeding station [19]. AMFs allow for 24 h access to milk feeding, and can be used to increase milk intakes through increased feeding bouts or the provision of milk ad libitum which can result in significantly higher growth rates than restricted milk feeding diets [20]. The feeding patterns on an AMF can also more closely mimic natural feeding patterns when calves are dam-reared, where suckling bouts occur 4–10 times per day [21]. The group housing needed for AMFs is beneficial for socialisation, with calves known to make long-lasting social relationships from a young age [22–24]. However, studies on group sizes of 12–18 calves have suggested a negative effect on growth rates and respiratory disease occurrence [25]. In adult cattle, competition at feeders results in a large proportion of displacements, indicating that gaining access to feed is of high priority, leading to competition [26]. This same behaviour pattern has been reported in calves fed on an AMF, with high levels of competition causing a lower duration of time spent ingesting milk, but not affecting the total amount of milk consumed [27].

The weaning period allows for the transition of calves from a predominantly liquid-based diet to only solid feeds. There are multiple weaning programs, with selection to wean based on age or solid feed intake, and methods including abrupt milk removal, gradual step-down programs and the dilution of milk concentration. Generally, gradual step-down weaning over at least a 10 day period [28] can increase solid feed intakes [29] to aid rumen development; however, this has been linked to increases in cross sucking [30]. Weaning is generally considered a stressful period, which may lead to changes in social behaviours and interactions within a group setting.

Whilst there is increasing literature to describe the effects of group housing, AMFs and weaning systems, the interaction and effect of other factors has not frequently been addressed. Most studies utilise single-sex dairy calves [5,15,31–33], with three studies having mixed-sex grouping [16,27,34], and one including mixed dairy and beef cross breeds [25]. There can be physical size and temperament differences between the sexes and breeds [35], as well as disease impacting calf behaviour, which may impact the overall feeding patterns and behavioural interactions within large groups. Using an in-depth study of groups of calves, this paper aimed to clarify how the composition of group-housed calves may impact the social interactions within a group, helping to understand the factors affecting calf growth, health and productivity within group housing situations, specifically from birth to 6 months of age to cover the periods prior to, over and following weaning.

2. Materials and Methods

2.1. Study Subjects

The study was carried out on a single commercial dairy farm in the south of England, UK, milking 200 cows, with data collected from March to September 2021. The farm had an all-year-round calving pattern, with both Holstein Friesian (HF) and HF cross beef breed calves of both sexes reared. A convenience sample of calves was recruited at birth if they were born within the study timeframe, and then followed through until six months of age.

Calves were removed from their dams at 12 h of age and moved into one large shed containing all animals up to approximately 3 months of age. The shed measured 40 m × 28 m, with compressed hardcore flooring throughout. The shed had space boarding along three walls with the front of the shed open, and a positive pressure ventilation tube along the centre. There was artificial lighting throughout the shed, and all pens were bedded with unchopped straw. The calves were initially housed in square pens made using gates, measuring approximately 10 m^2, and arranged in rows with gaps between pens to prevent nose-to-nose contact. The shed contained 10 of these small pens. Here, the calves were housed in groups of five for approximately three to four weeks. Whilst in the small pens of five calves, they were manually fed 3 L of milk replacer (26% whey protein, 17% fat, ForFarmers, Bury St Edmunds, UK) mixed at 150 g/L, fed twice daily through teat feeders.

Once there were three or four small pens of calves that were all deemed by the farmer to be feeding well, they were transferred into a single large pen as a group of 15–20 calves at approximately three to four weeks of age, and were fed using an AMF (Lely Calm, Lely, Birmingham, UK). Due to this grouping process, there was an age range of up to three weeks between the oldest and youngest calf forming the larger group, but the group then remained stable; Group 1 (G1)'s age onto the machine had a median of 23 days and an IQR of 8 days, Group 2 (G2)'s age onto machine had a median of 35 days and an IQR of 5 days. The shed contained five large pens arranged in a row, each measuring 18 m by 4.5 m, and separated by gates which enabled nose-to-nose contact between large pens. A total of two large pens of calves were followed in this study. The first group was established in April and the second in May. At three months of age, the whole group of calves were moved to a separate loose-housed and straw-bedded shed, where they remained within the same group cohorts until six months of age.

The calves were weighed at birth by the farm staff, and then by the researcher (SM) weekly until 12 weeks of age using an electronic weigh crush (Bateman, Staffordshire, UK) to allow for the calculation of weekly growth rates, with an additional weight taken at six months of age. The researcher undertook a weekly clinical health assessment from 1 to 12 weeks of age following the Wisconsin scoring system to assess demeanour, nasal and ocular discharge, cough, faecal consistency, rectal temperature and navel and joint health [36]. A diagnosis of pneumonia was given when a calf displayed at least one sign of upper respiratory disease (nasal/ocular discharge or cough) and pyrexia ($\geq$39.5 °C). The overall disease score was then simplified to a binary classification of disease, being either present (score 1) or absent (score 0) [37,38], and split by time occurrence to being either prior to grouping on the AMF, or whilst grouped on the AMF. When calves were identified as ill, they were treated according to standard veterinary practices by the farm staff.

2.2. Nutrition

Within the large group pens, calves were fed the same powdered milk replacer (26% whey protein, 17% fat, made by ForFarmers, Bury St Edmunds, UK) through a single teat feeding station per pen from the AMF. Calves had nearly ad libitum access to milk rations, with maximum portion sizes of 3.0 L available every three hours, meaning calves could theoretically consume up to 21 L of milk each day. This was provided immediately upon entering the AMF group up to 8 weeks of age. Calves were then entered onto a step-down weaning program, taking them from 7.0 L to 0.0 L of milk over a two-week period, such that calves were fully weaned off milk at 10 weeks of age. This was managed by individual calf ages, resulting in the entire group being weaned once the youngest calf reached 10 weeks of age.

The number of rewarded (when the calf visited the feeder and received milk) and unrewarded (when the calf visited the feeder but did not receive milk) visits to the feeding station was recorded daily [39], along with the amount of milk powder consumed. Calves also had ad libitum access to pelleted concentrates in troughs (21% protein, ForFarmers, Bury St Edmunds, UK), hay in a rack and an automatic water trough. Post weaning, the calves remained on ad libitum access to concentrates and hay until 4 months of age, followed by 2 kg/day concentrates and ad libitum access to maize silage and hay until 6 months of age.

2.3. Activity Data Collection

All calves had tri-axial accelerometers (IceQube, Peacock Technologies, Stirling, UK), fitted to either hind leg within one week of age, and removed at 13 weeks of age. These data loggers have been validated for research on calves [40] and measured the lying times, lying bouts, standing times and motion index (MI), which is a measure of the intensity of the movement of the calves.

2.4. Behavioural Data Collection

Video cameras (Hik-Vision, Hangzhou, China; four per pen) were placed overhead in the calf barn to provide footage for approximately 2 m around the AMF station. Individual calves were identified through the use of coloured stock markers on their backs. Continuous focal sampling of the footage was conducted using the software Behavioral Observation Research Interactive Software (BORIS, version 7.9.6 [41]). The calves were observed for one day each week during daylight hours 06.00 h to 19.00 h over a seven-week period covering the two weeks prior to weaning, the two weeks of weaning and the three weeks following weaning. This produced 14 pieces of video footage, each 13 h in length. During the video observations, calf behaviour was recorded according to the ethogram shown in Table 1. The social aspects of feeding behaviour were documented using adjacency matrices to record the proximity of individuals carrying out different behaviours. Two interactions between the same calves were treated as one interaction if there was a break of less than 20 s between them [42]. All observations were carried out by the same researcher (SM).

Table 1. Description of recorded behaviours for calves, both social interaction and point-based behaviours [27,43,44].

Behaviour	Description
Calf in milk feeder	A calf had a minimum of both front feet over the wooden barrier demarcating the entrance to the milk feeder.
Social milk feeding	A calf (the initiator) was within one calf length of the AMF station whilst another calf was feeding (the receiver). The initiator and receiver were recorded in a directed adjacency matrix.
Displacement behaviour towards a calf in the milk feeder	A calf (the initiator) head butting, rubbing or mounting a calf (the receiver) that was within the milk feeder. The initiator and receiver were recorded in a directed adjacency matrix.
Occurrence of cross sucking near milk feeder	A calf performing non-nutritive sucking directed to the ventral body of another calf. The calves were recorded in an undirected adjacency matrix.

Social network analysis methodology was used to assess the importance of individual calves and characteristics within a network (group of calves) [45]. For the behavioural analysis around the AMF, the mean number of calf interactions (preferential associations) were calculated for each adjacency matrix and found to be in the range of 0.04–1.3 average interactions at the milk feeder per day (the mean value was low as not every calf fed with every other individual). As used by others [44,46–48], a threshold for the number of interactions was then set at $\geq$2 interactions between an initiator and the same recipient to account for random interactions and the nature of weighted data in the analysis of calves feeding together. The raw interaction numbers were used in the displacement and cross sucking behaviour analysis due to the low overall number of interactions occurring.

To assess the preferential associations of calves near each other whilst feeding in the AMF (i.e., Did calves like to feed with other specific calves?), and for cross sucking (i.e., Did calves prefer to cross suck with other specific calves?), the degree centrality was calculated. This shows the number of behavioural interactions that a calf had within the network [49], and indicated their social prominence [50] and ability to directly influence other calves. Calves with a high degree centrality indicate higher social prominence [51,52].

2.5. Statistical Analysis

A sample-size calculation was conducted to enable the identification of a 70 g/day growth difference between calves [53], which indicated that a minimum sample size of 10 animals per group was required. Given the AMF group size on the study farm was 15–20 calves, all calves within two separate groups were enrolled, ensuring an adequate sample for this observational study. All analyses were conducted using SPSS (version 28.0, IBM SPSS Statistics for Windows, IBM Corp, New York, NY, USA). Sociograms from the adjacency matrices for behaviour around the milk feeder were constructed using Visone (Version 2.2 [54]). The analysis of the data was conducted using UCINET (Version 6.773 [55]). Normality was assessed through the visual inspection of residual plots.

Linear mixed effects models were used to analyse the outcomes of average milk powder ingestion per day and average daily liveweight gain (ADLG). The breeds were split into beef and dairy breeds, and disease was summarised into the periods prior to and during time on the AMF rather than by week of the study, with binary coding of either diseased or healthy. The overall fixed effects included sex, breed, presence of disease prior to and whilst on the AMF and birthweight. The unique calf identification number and group were included as a random effect. The results are reported as F-values in the format $F_{(\text{numerator df, denominator df})}$. No interaction parameters where assessed as there was no indication that a change in any of the variables would specifically effect any of the other variables prior to the assessment of the results.

Generalised estimating equation linear models with an identity link function and an exchangeable working matrix were used to analyse the repeated outcomes of the number of successful visits and the number of refusals within the AMF station. The variables included sex, breed, group, disease occurrence prior to and during being on the AMF, birthweight and age onto the milk machine. The unique calf identification number was used to account for the repeated measures over time.

Generalised estimating equation gamma log link models for positively skewed data and an exchangeable working matrix were used to analyse the outcome of activity, which accounted for the repeated measures of motion index, lying times and number of lying bouts per day. The variables included sex, breed, group, disease occurrence prior to and during being on the AMF, birthweight and average daily liveweight gain. The unique calf identification number was used to account for the repeated measures over time. Through the use of the gamma log link, variables were transformed to a log scale for modelling, with the coefficients then undergoing exponentiation on a natural log scale to provide results on a numerical scale for interpretation.

The effect of week, sex, breed and disease on the degree centrality for calf interactions at the AMF between weeks, and for the occurrence of cross sucking, was assessed using the Kruskal–Wallis analysis for non-parametric data.

Behaviour around the milk feeder was analysed using a Galindo–Broom displacement index (DI), and was calculated based on the proportion of displacements an animal initiated compared to the total number of displacements in which the animal was involved [26,56,57]:

$$\text{Displacement Index} = \frac{\text{Number of times the individual displaced any calf}}{\text{Number of times individual displaced calf} + \text{number of times individual was displaced}}$$

Calves with a DI below 0.4 were classified as low-ranking, between 0.4 and 0.6 were considered middle-ranking calves and those with a DI greater than 0.6 were considered high-ranking [56]. Prior to analysis, a logit transformation was used for the DI, followed by a generalised estimating equation analysis with an identity link function and an exchangeable working matrix. The dependent variables were pen, sex, breed, binary disease occurrence prior to and during being on the AMF, birthweight and mean milk powder consumption per day. The unique calf identification number was used to account for the repeated measures over time. The coefficients underwent inverse logit transformations to present results as the percentage change in DI.

3. Results

A total of 36 calves were recruited at birth between February and March 2021. During the study, 4 calves died whilst in the small pens of 5 calves, leaving 32 calves in the analysis. There were 19 calves in Group 1 and 13 calves in Group 2, with descriptive information about the groups in Table 2. Most were HF dairy breeds, but there were also four male beef cross breed calves; their data was retained within the models as they interacted with the other calves, but due to their low numbers, results relating to potential breed differences need to be interpreted with caution. The mean birthweights were slightly higher in the beef compared to dairy breeds (48.8 ± 5.3 kg compared to 46.5 ± 5.9 kg), which mirrors the overall heavier birthweight in male compared to female calves (48.6 ± 6.3 kg compared to 45.5 ± 5.2 kg).

Table 2. Descriptive information regarding the calf groups on the AMF.

Variable	Group 1	Group 2	Overall
Female:male calves	13:6	6:7	19:13
Breed Dairy:Beef X	17:2	11:2	28:4
Mean birthweight (range), kg	47.5 (40.0–60.0)	45.8 (34.0–52.0)	(34.0–52.0)
Mean age onto AMF (range), days	21.8 (15.0–28.0)	33.9 (27.0–40.0)	(15.0–40.0)
Mean days fed on AMF (range), days	49.3 (42.0–56.0)	38.2 (31.0–45.0)	(31.0–56.0)
Mean milk powder ingested per day (range), kg/calf	1.4 (1.1–1.7)	1.1 (0.7–1.5)	1.3 (0.7–1.7)
Mean total milk powder ingested (range), kg/calf	67.4 (53.0–91.0)	41.9 (26.0–66.0)	57.1 (26.0–91.0)
Mean ADLG (range), kg	0.89 (0.71–1.03)	0.87 (0.62–1.14)	0.89 (0.62–1.14)
Disease prevalence prior to AMF(%)	1/19 (5.3)	2/13 (15.4)	3/32 (9.4)
Disease prevalence whilst on AMF(%)	6/19 (31.6)	2/13 (15.4)	8/32 (25.0)

Overall disease prevalence based on weekly scoring up to 12 weeks of age was 34.4% (11/32), with 7/32 calves developing pneumonia (5 from G1, 2 from G2), 2/32 calves developing diarrhoea (both from G2) and 2/32 calves developing diphtheria (both from G1). All cases of disease were only detected via calf scoring for a duration of one week, with no recurrences detected. There were no new cases of disease in any calves following week 8 on the AMF.

Milk powder consumption included the set feeding rate of 900 g/day whilst the calves were hand-fed in small groups, plus the individual feeding rates once the calves were moved onto the AMF. In general, the calves in Group 2 were older when put onto the AMF, resulting in less overall access to milk.

3.1. Milk Feeding Analysis

The calves consumed a mean of 1.3 kg (range 0.7–1.7 kg) of milk powder per day, equivalent to 8.7 L of milk (Figure 1). The model for average daily consumption demonstrated no associations with birthweight, p = 0.52; sex, p = 0.92; breed, p = 0.22; disease occurrence prior to entry to the AMF, p = 0.60 or disease occurrence after entry onto the AMF, p = 0.72.

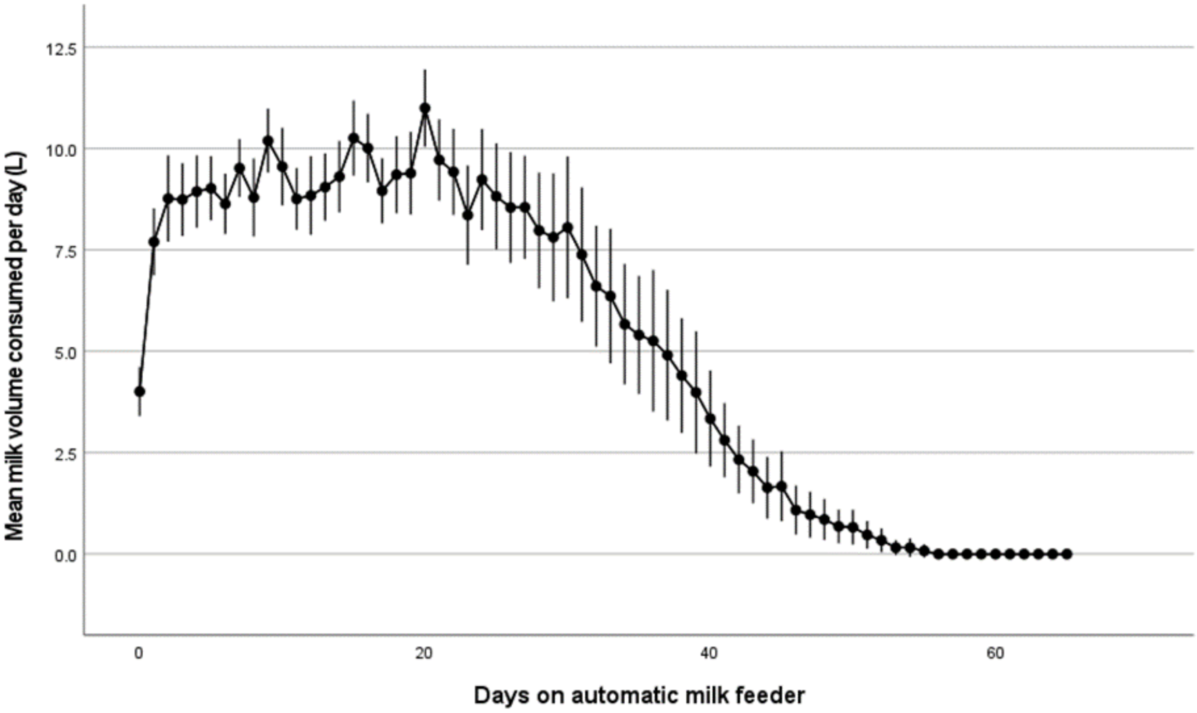

Figure 1. The change in mean milk volume ingested per day (L) whilst calves were fed on the AMF (n = 32 calves), with 95% confidence intervals. The calves entered a step-down weaning program after approximately 30 days on the AMF, and this weaning phase lasted approximately 14 days.

The ADLG up until 24 weeks of age was 0.89 kg/day (range 0.14 to 2.23 kg/day), with ADLG pre-weaning being 0.74 kg/d (SD 0.41 kg), rising to 0.99 kg/d (SD 0.46 kg) over weaning and 1.05 kg/d (SD 0.12 kg) in the post-weaning period. Overall, the ADLG increased with age, but with a wide variation between individuals (Figure 2). Sex was significantly associated ($F_{(1,25.9)}$ = 10.3, p = 0.004) such that male calves had a higher ADLG than female calves (0.92 kg/day compared to 0.79 kg/day). The mean overall ADLG was not associated with disease occurrence prior to entry to the AMF (p = 0.23), but was significantly associated with disease occurrence whilst on the AMF. Calves experiencing disease had a lower overall ADLG from birth to 6 months of age of 0.81 kg/day compared to healthy calves with 0.90 kg/day ($F_{(1,25.8)}$ = 5.9, p = 0.022). The remaining independent variables demonstrated no significant association with ADLG; birthweight p = 0.60 and breed p = 0.35.

The mean number of successful visits to the AMF per day (visits that resulted in milk being supplied to the calf) was 2.9 (range of 0–13), with an overall decrease over time (Figure 3). The analysis demonstrated a significant association with sex (p = 0.014), with female calves having an increased number of successful visits compared to males (mean 3.7 compared to 3.1 successful visits) (Table 3). The calves that experienced disease prior to entry onto the AMF had more successful visits to the AMF (3.8 visits compared to 2.9 visits, p = 0.046). The age the calves went onto the AMF was also significantly associated with the number of successful visits (p = 0.005), with a 1-day increase in age giving a 7.8% reduction in successful visits to the AMF.

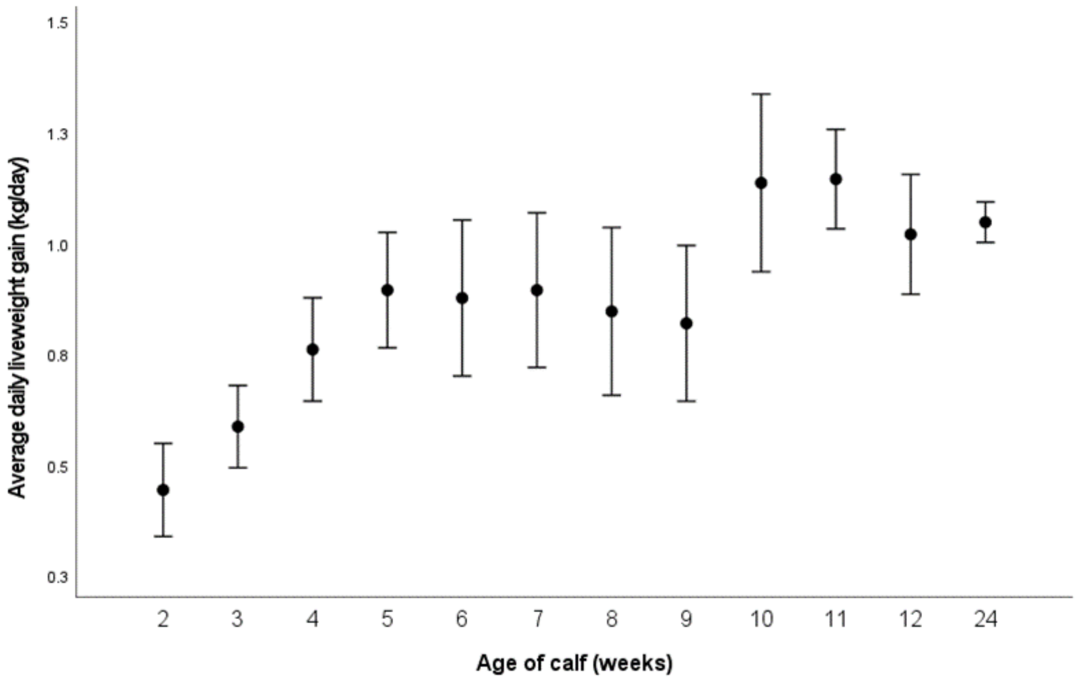

Figure 2. Mean ADLG of the calves calculated on a weekly basis (*n* = 32 calves), with 95% confidence intervals. The ADLG increased steadily over the first month of life, appeared to become more stable once calves were fed via the AMF and then increased again post weaning.

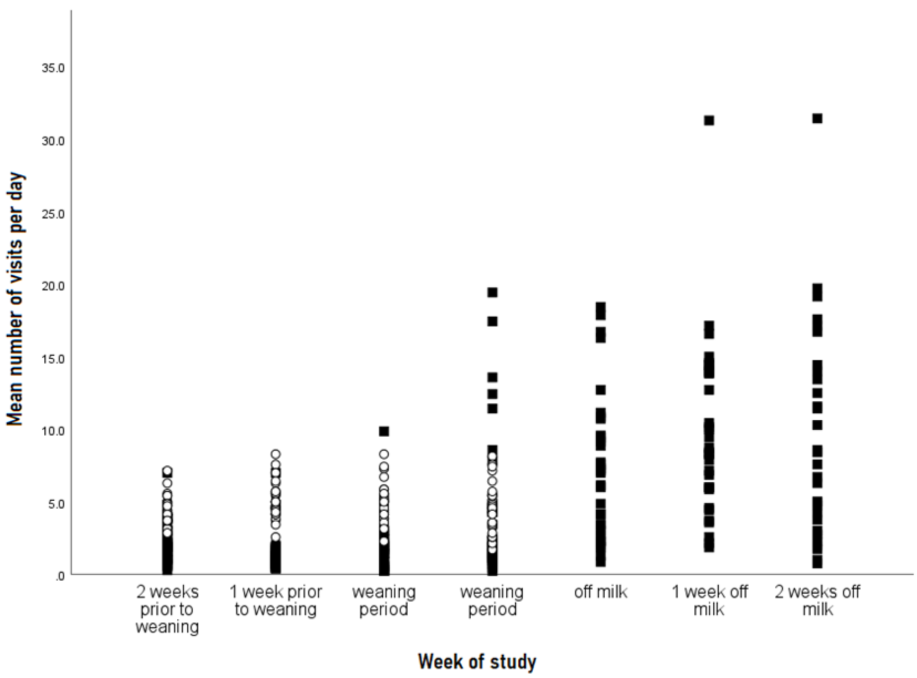

Figure 3. Mean number of successful visits (white circles) and refusal visits (black squares) to the AMF made by calves each week in relation to the milk feeding period. Each marker represents the mean value for one calf.

Table 3. Parameter estimates for the associations between successful (visits that resulted in milk being supplied to the calf) and refusal (visits that did not result in milk being supplied to the calf) visits to the AMF derived from generalised estimating equation linear models. For sex, male was used as the baseline group; for breed, beef was used as the baseline group; for study group, Group 2 was used as the baseline group; for disease, being diseased was used as the baseline group. Significance is at $p < 0.05$ *.

Independent Variable	Successful Visit (SE), *p*-Value	Refusal Visit (SE), *p*-Value
Birthweight	0.026 (0.019), 0.17	0.047 (0.037), 0.20
Sex	0.60 (0.24), 0.014 *	2.05 (0.59), <0.001 *
Breed	−0.30 (0.22), 0.16	−1.38 (0.61), 0.023 *
Disease prior to AMF	−0.89 (0.45), 0.046 *	−1.10 (0.73), 0.13
Disease whilst on AMF	−0.042 (0.24), 0.86	−1.03 (0.51), 0.042 *
Age onto AMF	−0.078 (0.028), 0.005 *	−0.019 (0.096), 0.85
Group	0.005 (0.36), 0.99	0.067 (1.20), 0.96

The mean number of daily refusal visits to the AMF (visits that did not result in milk being supplied to the calf) was 4.9 (range of 0–46), with increasing visits over the weaning period (Figure 3). The analysis demonstrated a significant association with sex, with female calves having increased refusal visits compared to males (6.7 refusals compared to 5.0, $p < 0.001$). Calves with disease whilst on the AMF had decreased numbers of refusals compared to healthy calves ($p = 0.042$), but refusal visits were not impacted by disease prior to being on the AMF ($p = 0.13$).

3.2. Activity Analysis

Data from two calves were not included due to loss of the accelerometer, leaving data from 30 calves in the analysis (Table 4). The median overall lying time per day was 16 h 49 min (range 8 h 27 min to 23 h 2 min), with a general decrease in lying times as the calves aged (Figure 4). The analysis demonstrated a significant association with breed ($p = 0.002$), with beef cross calves having longer lying times than the HF dairy calves (17 h 40 min compared to 17 h 03 min). Calves experiencing disease prior to entry onto the AMF had longer lying times than healthy counterparts (18 h 17 min compared to 17 h 13 min, $p = 0.005$), but were not impacted by disease occurring whilst on the AMF ($p = 0.45$). Heavier birthweight calves also had lower lying times per day ($p < 0.001$), with a 1 kg increase in birthweight resulting in a 6.91% decrease in lying time per day.

Table 4. Parameter estimates (percentage change) for activity parameters in calves housed in groups on an automatic milk feeder (AMF) derived from generalised estimating equations with gamma log link models. Data are presented on a numerical scale. For sex, male was used as the baseline group; for group, Group 2 was used as the baseline group; for disease, being diseased was used as the baseline group. * indicates significance at $p < 0.05$, # indicates a trend at $p < 0.1$.

Independent Variable	Motion Index (SE), *p*-Value	Lying Time per Day (SE), *p*-Value	Lying Bouts per Day (SE), *p*-Value
Birthweight	−0.97 (5.91), 0.82	−6.21 (7.26), <0.001 *	5.81 (5.88), 0.35
Sex	−3.44 (3.10), 0.46	−4.06 (4.41), 0.16	3.20 (2.95), 0.43
Breed	2.29 (3.18), 0.023 *	−3.32 (4.41), 0.002 *	3.50 (2.60), 0.68
Disease prior to AMF	1.84 (2.73), 0.024 *	−3.10 (4.18), 0.005 *	2.38 (3.00), 0.076 #
Disease whilst on AMF	2.59 (3.13), 0.098 #	−4.70 (4.41), 0.45	3.06 (3.34), 0.19
Group	−3.44 (3.26), 0.41	−4.12 (4.50), 0.13	−2.5 (3.31), 0.034 *
ADLG	−0.97 (1.82), 0.056 #	−6.91 (2.65), 0.98	0.54 (1.13), 0.13

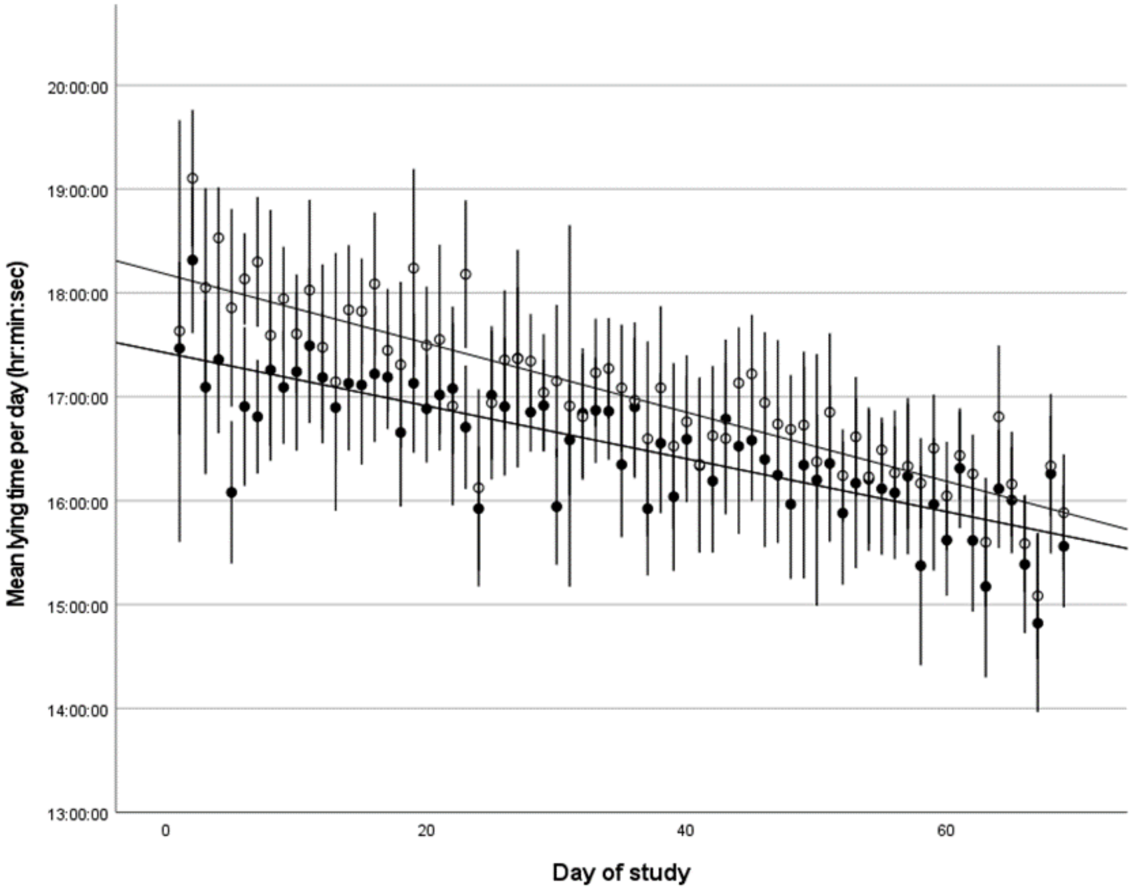

Figure 4. Mean lying time per day over the study period with 95% confidence intervals is shown (n = 30 calves). Females are denoted by black circles and males by white circles. As the calves got older, their lying times reduced (r^2 = 0.66 for females, r^2 = 076 for males).

The median overall number of lying bouts per day was 20 (range of 6–42) and was associated with the group on the AMF (p = 0.034), with G2 having more lying bouts that G1 (20.5 bouts compared to 19.6 bouts) (Table 4). There was also a trend with the occurrence of disease prior to being on the AMF (p = 0.076), with calves experiencing disease having more lying bouts than healthy calves (20.9 compared to 19.2 bouts).

Accelerometer data were used to assess the amount of time calves spent standing (whilst being either stationary or moving) over the mean 24 h period (Figure 5). A diurnal pattern was visible, whereby calves were more active during the morning and afternoon periods.

The median overall motion index (MI) for the 12-week monitoring period was 4991 (range per day 294–25,515). The analysis demonstrated a significant association with disease status of the calf prior to entry onto the AMF (p = 0.024), with calves that experienced disease having a lower mean motion index (4520 compared to 5185). There was also a trend with disease occurrence whilst on the AMF (p = 0.098), again with a lower mean motion index in diseased calves (4675 compared to 5013). Breed was associated with MI (p = 0.023), with beef calves having a lower MI than dairy calves (4624 compared to 5068). There was also a trend with overall growth (p = 0.056), with a 100 g increase in weight leading to a 0.97% decrease in MI.

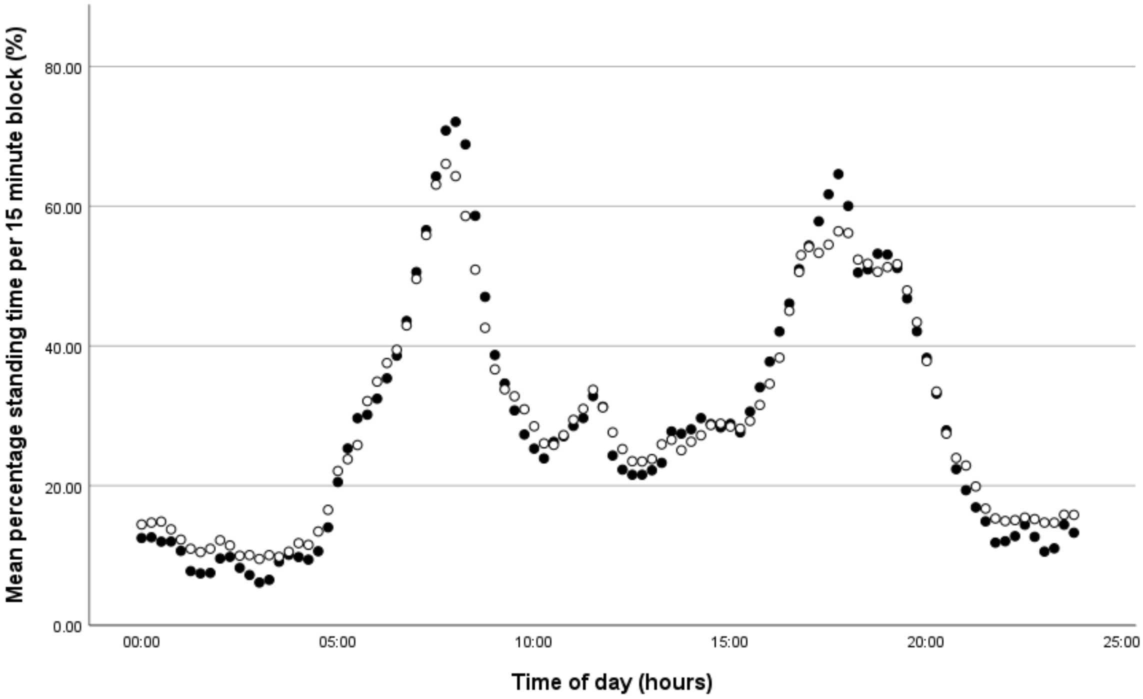

Figure 5. Accelerometers attached to the rear legs of calves (*n* = 30 calves) measured standing time in 15 min intervals throughout the day. These data were averaged across the study period from 1 to 12 weeks of age. The graph illustrates the mean percentage of time within each 15 min block that the calves spent standing (this includes both moving and stationary) over the course of the average day. White circles represent healthy calves (*n* = 19) and black circles represent calves who experienced disease (*n* = 11).

3.3. Behavioural Analysis

The observation time totalled 182 hrs for all behavioural video analyses. The total numbers of observations and descriptive information are given in Table 5. The analysis of the preferential association networks for calves near each other whilst feeding in the AMF enabled the social prominence of a calf to be established [50]. Calves with a high degree centrality indicated a calf with higher social prominence [51,52]. Changes in degree centrality between the weeks of the study ($\chi^2(6) = 60.0$, $p < 0.001$) indicated that being socially prominent was a transient social state, with an overall increase in centrality figures across the weaning period (Figure 6). There was a trend with sex ($\chi^2(1) = 2.70$, $p = 0.10$), with females having a higher median degree centrality compared to males (5.0 compared to 4.0). There was also a trend with disease occurrence whilst on the AMF ($\chi^2(1) = 3.52$, $p = 0.06$), with sick calves having a higher median degree centrality than healthy calves (4.0 compared to 7.0). There was no association with breed ($p = 0.55$) or disease prior to being on the AMF ($p = 0.96$).

Table 5. Summary of the number of observations within each adjacency matrix for the behaviours of being near the AMF when a calf is feeding, displacements from the AMF and cross sucking near the AMF. Group 1 had 19 nodes (calves per group) and Group 2 had 13 nodes.

Behaviour	Observation Type	2 Weeks before Weaning	1 Week before Weaning	Weaning	Weaning	Off Milk	1 Week Off Milk	2 Weeks Off Milk
Group 1 Near AMF	Total in group	23	133	77	38	63	128	147
	Min–max per calf	0–2	0–7	0–4	0–3	0–3	0–10	0–6
	Average per calf	0.067	0.389	0.225	0.111	0.184	0.374	0.43
Group 1 Displacements from AMF	Total in group	41	2	16	27	16	2	0
	Min–max per calf	0–3	0–2	0–1	0–2	0–3	0–1	0–0
	Average per calf	0.12	0.085	0.047	0.079	0.047	0.006	0
Group 1 Cross sucking	Total in group	18	11	24	32	10	1	0
	Min–max per calf	0–2	0–2	0–3	0–5	0–2	0–1	0–0
	Average per calf	0.053	0.032	0.07	0.094	0.029	0.003	0
Group 2 Near AMF	Total in group	38	37	16	18	116	4	22
	Min–max per calf	0–4	0–3	0–3	0–2	0–6	0–1	0–3
	Average per calf	0.244	0.237	0.103	0.115	0.744	0.026	0.141
Group 2 Displacements from AMF	Total in group	3	25	4	19	30	7	5
	Min–max per calf	0–1	0–3	0–1	0–4	0–4	0–2	0–1
	Average per calf	0.009	0.073	0.012	0.056	0.088	0.021	0.015
Group 2 Cross sucking	Total in group	18	14	20	55	60	26	22
	Min–max per calf	0–3	0–2	0–4	0—5	0–7	0–3	0–2
	Average per calf	0.053	0.041	0.058	0.161	0.175	0.076	0.064

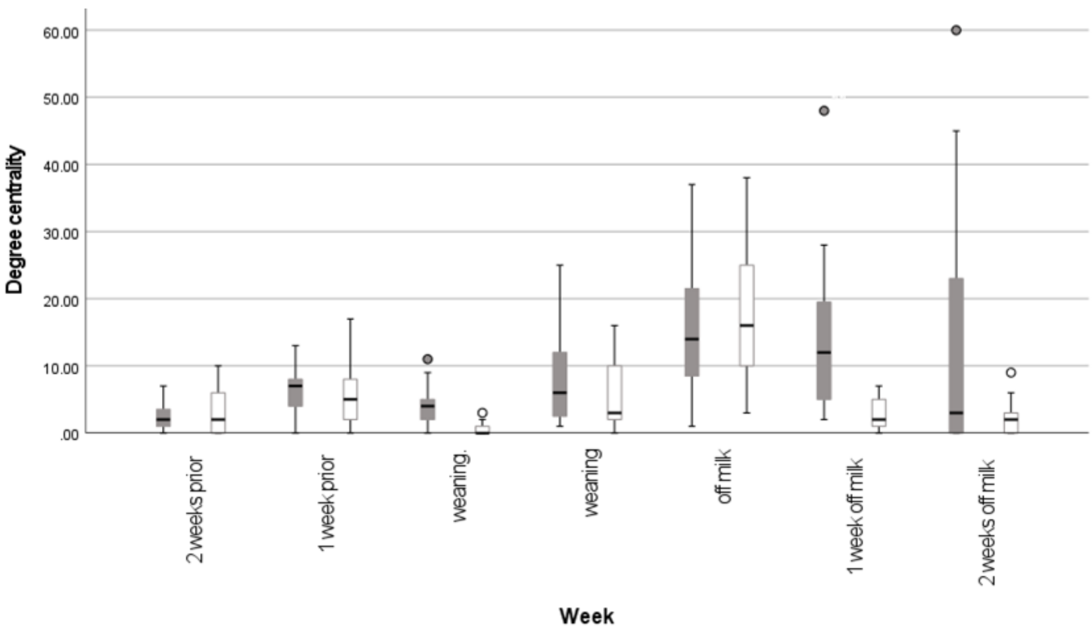

Figure 6. Distribution of the degree centrality for calves near the AMF by week of observation. Dark bars indicate calves in G 1 (n = 19 calves) and white bars indicate calves in G2 (n = 13 calves). The box and whisker plots show the median degree centrality for the calves in each group, the upper and lower quartiles for degree centrality and the upper and lower extremes, as well as any outliers (grey outlier circles are for G1, white outlier circles are for G2). It demonstrates that the degree centrality becomes more widely distributed during and after the weaning period, especially for calves in Group 1.

The assessment of the displacement index from the AMF varied by week (Figure 7), with the most notable change occurring once milk was withdrawn from the calves following weaning, resulting in a decrease in DI amongst calves. There was a trend associated with sex (B = 0.094 (SE 0.054), p = 0.082), with female calves having a higher mean DI than male calves (0.39 (SE 0.047) compared to 0.28 (SE 0.030)). There was no association with breed (p = 0.71), disease occurrence either prior to (p = 0.69) or whilst being on the AMF (p = 0.68) or mean daily milk powder consumption (p = 0.83).

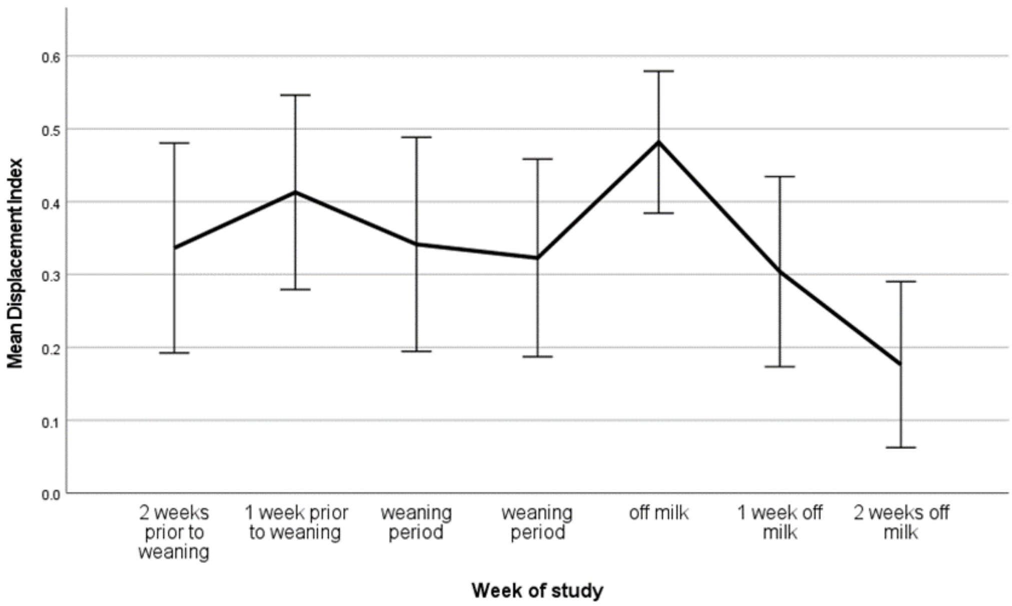

Figure 7. Mean displacement index of all calves across the study period (n = 32). Error bars represent the 95% confidence interval.

For the analysis of cross sucking, events were carried out by most calves within the group. The model for degree centrality indicated that being socially prominent in carrying out cross sucking was a transient social state due to changes in degree centrality between weeks ($\chi^2(6) = 66.6$, $p < 0.001$), with an overall increase in cross sucking occurrences across the weaning period (Figure 8). The breed of the calf was significantly associated with the cross sucking degree centrality ($\chi^2(1) = 9.8$, $p = 0.002$), with beef calves having a higher median value than dairy calves (5.0 compared to 4.0, Figure 9). There was a trend with the sex of the calf ($\chi^2(1) = 3.5$, $p = 0.06$), with females having a higher median compared to males (5.0 compared to 4.0). There was no association with disease occurrence prior to ($p = 0.12$) or whilst on the AMF ($p = 0.54$).

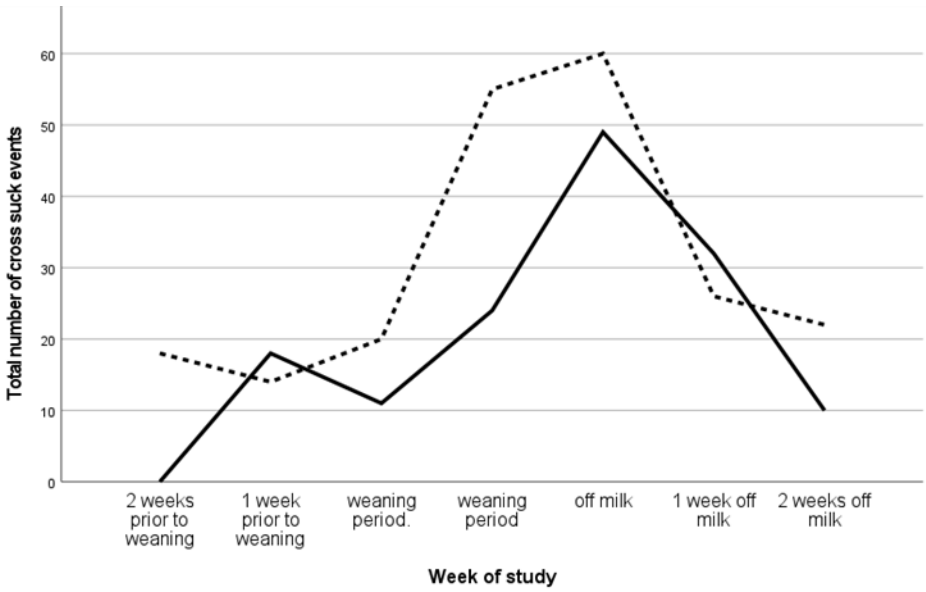

Figure 8. Total number of cross sucking occurrences in each week of the study. The solid line indicates calves in Group 1 ($n = 19$) and the dotted line indicates calves in Group 2 ($n = 13$).

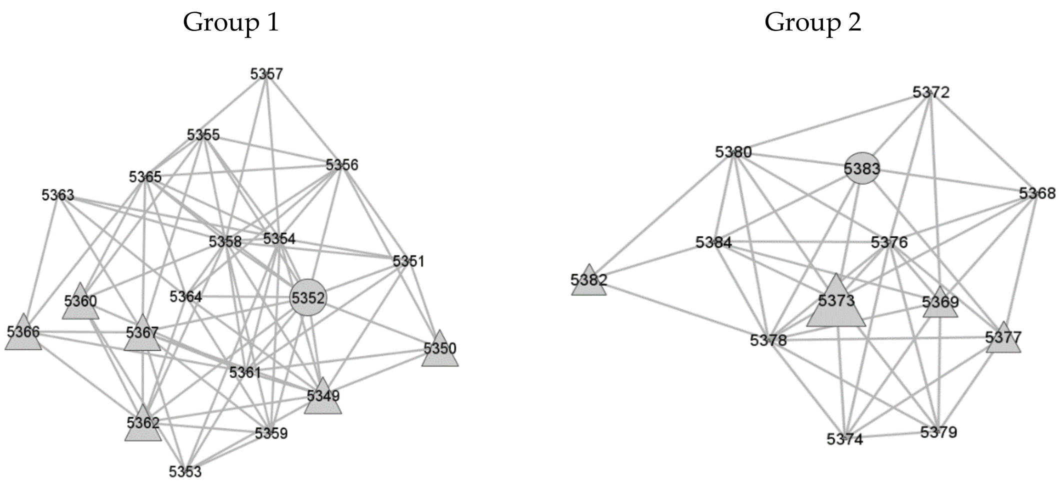

Figure 9. Undirected sociograms showing the preferential interactions between socially dominant calves when cross sucking, with data combined over all seven weeks. Each calf has a unique node to identify it within the sociogram. The Kruskal–Wallis analysis demonstrated that the breed was significantly associated with cross sucking interactions; therefore, these categories are depicted by the shapes of the nodes, but only for calves with a degree centrality (social prominence) above the 95% confidence interval range (circle for beef x, triangle for dairy).

4. Discussion

This observational study followed two groups of calves fed on an AMF to assess the health, feeding patterns and social behaviours prior to, over and following the weaning period. It was based on a single commercial farm study managed under the guidelines stipulated by two farm assurance schemes which are used widely in the UK (Red Tractor, https://redtractor.org.uk/ and Arla, https://news.arlafoods.co.uk/sustainable, accessed on 30 May 2023) which cover around 95% and 27% of UK dairy farms, respectively. The single farm setting ensured both groups were followed under exactly the same management and environmental conditions. Activity monitors provided data throughout the 24 hr period, but behavioural analysis was not possible during the night as we did not wish to use artificial lighting to enable accurate calf identification at this time. This was a limitation as the AMF recordings demonstrated that, although milk feeding predominantly occurred during daylight hours, the calves continued to feed during the night. The social network analysis assessed the probabilities of finding calves preferentially together near the AMF at greater-than-chance levels, but it is possible that a lack of observations during the night period reduced the ability to find medium- or low-strength preferential associations. The behavioural assessments also only included the area immediately surrounding the AMF, so additional behaviours might have occurred away from this site which have not been taken into account in this study.

During the milk feeding phases, the mean number of daily visits to the AMF was 2.9 (range of 0–13) and the mean milk powder consumption by the group was 1.3 kg/day (or ~8.7 L/day). This roughly translates to an average of three milk feeds of 3 L per calf per day being consumed. Each individual feed was limited to a maximum of 3 L by the AMF. This voluntary milk intake figure is in line with those found by other researchers [58–60]. A recent UK farmer survey indicated that 87.5% (189/216) of farmers only fed their calves twice daily, with 93.5% feeding $\leq$ 8 L of milk per day [61]. This highlights the current widespread underfeeding of milk across the UK. Restricted milk feeding has been found in other studies [62,63], with farmers often citing ease of management as a reason for their chosen feeding regime [64]. The use of AMFs is still relatively low in the UK [61] and Ireland [63] at around 4% of farms, but these systems do offer a method for increasing milk intakes without the associated labour impacts.

The ADLG until weaning was 0.89 kg/day, which is above the minimum recommendation of 0.75 kg/day if a replacement dairy heifer is to achieve adequate bodyweight in order to calve at 24 months of age [65]. However, it was lower than the ADLG in excess of 1 kg/day for calves fed accelerated milk quantities found by [58]. This may have been due to the relatively high motion indexes found in this study, with calves having a lot of room (4 m^2 per calf), possibly leading to energy usage through increased activity. Disease occurrence whilst on the AMF did significantly reduce ADLG from 0.90 kg/day in healthy animals to 0.81 kg/day in sick calves. Interestingly, the disease prevalence in the smaller group size (n = 13) was 6% lower than the larger group size (n = 19), along with more pneumonia cases within the larger group. This is in line with the findings from [25], who found lower respiratory disease levels in smaller group sizes, possibly due to less direct contact between lower numbers of calves, and fewer calves feeding from the same teat which can act as a risk factor for disease spread through contaminated secretions from the respiratory tract.

Overall, male calves had higher birthweights, and although there was no significant increase in mean milk powder consumption, they still had a higher mean ADLG compared to female calves. However, female calves paid more visits to the AMF overall, including more successful and refusal visits. The social analysis also established that females had a trend towards higher displacement indexes, meaning that they tended to be the recipient of more aggressive behaviours whilst in the AMF. This is in line with [66], who found that male calves are more active in mounting and pushing behaviours than female calves. This study did not collect data on meal sizes, but the available feeding pattern would suggest that, although female calves paid more frequent visits to the AMF, they consumed smaller meal sizes at each successful visit, possibly due to their higher displacement levels. It was also noted that male calves with a heavier birthweight had longer lying times, also found by [67], which may have contributed to decreased energy expenditure from activity. Overall, this suggests it may be better to group calves in single sexes to avoid any bullying behaviour of males towards females.

The overall mean number of refusal visits to the AMF was 4.9 (range of 0–46), and these increased over the weaning period even though a gradual step-down weaning program was used, which is in line with other studies [60,68,69]. Although solid feed intakes were not measured, the ADLG was maintained and even increased over the weaning period, suggesting that calves were likely to be transitioning well onto a solid feed diet, so hunger should not have influenced AMF visits. Others have suggested frustration as an explanation for unrewarded refusal visits during and following weaning [60], with the removal of near-ad libitum access to milk resulting in a lack of expected milk rewards when a calf visits the AMF. There may also have been an impact on the difference in weaning schedule between group members, with some calves still eligible to receive milk, which may have encouraged fully weaned calves to visit the AMF as they observed other calves feeding.

The group housing of calves has shown variable effects on disease levels compared to individual housing [13], with this study finding 34.4% morbidity but no mortality whilst on the AMF. The size of calf groups is thought to have an impact on disease prevalence, with some reports of groups sizes > 7 having a negative impact on disease occurrence [25,70]. This study found that calves experiencing disease whilst on the AMF had a 0.09 kg/day lower ALDG than their healthy counterparts. Interestingly, calves that had been sick prior to entry onto the AMF were also found to have lower odds of completing successful visits to the AMF, but had no difference in refusal visits. This suggests that a calf's willingness to visit the feeder and voluntarily consume milk via an AMF can be negatively influenced by health events prior to entry onto an AMF. Calves that experienced disease whilst on the AMF did not alter the number of successful visits to the AMF (and did not reduce mean milk powder intakes), but they did have fewer refusal visits, which is in line with findings by others that sick calves do not feed as often [32,71–74]. It should be noted that this study utilised weekly health scoring, so it is possible some disease episodes were missed, resulting in a lower disease detection rate than the true on-farm prevalence.

The overall activity of the calves indicated a diurnal pattern, with peaks in standing clustered around morning and evening. There may have been some pre-conditioning of activity behaviour in these calves as they had received manual twice-daily milk feeding during their first few weeks of life. Preferential feeding at these times may have led to congestion around the single feeding point per pen on the AMF. Further research into feeding time patterns for calves using AMFs may be useful to establish optimal group sizes that minimise calf waiting times and the possible occurrence of negative social interactions at busy feeding periods.

Social interactions between calves were assessed for prominence (degree centrality) over time. Using these measures, we found no consistent evidence for calf feeding preferences between specific individuals, meaning a calf was as likely to feed at a similar time as any other calf in the group. The calves housed in groups use social facilitation whereby they initiate specific behaviours (such as using the AMF) while observing others engaged in that behaviour [75]. Given that our study found no calf preferences, it might be concluded that social facilitation is socially indiscriminate, meaning that any calf is equally likely to join another calf. This has been found in other species such as fowl [76], with birds housed in large groups not discriminating familiar from unfamiliar individuals [77]. In addition, it has been reported that group size can have an impact on social preferences, with larger group sizes exerting pressures due to increased social demands, possibly resulting in social indifference [78] and social tolerance of close proximity by any group member [79].

The levels of both social prominence, displacements and cross sucking increased over the weaning period. This is likely linked to the high number of refusal visits, with multiple calves within the group spending time in and around the AMF. This could again be linked to frustration, with calves wanting to consume milk but receiving reducing amounts over time. Cross sucking behaviours were generally low, but were carried out by most calves in the group, which is in line with [80] for calves fed via an AMF. The sex of the calf significantly impacted the degree centrality, adding weight to the argument for managing AMF groups as single sexes. There was an increased level seen in the beef cross calves, who were more prominent and influential in engaging in cross sucking than the dairy breeds. It should be noted, however, that there were only four beef cross calves. Finding a significant association with such low power therefore highlights an interesting difference, although the reason for it is unclear and may be a false positive due to the low power. Further studies should investigate this breed difference further to elucidate whether there is a benefit to group calves by breed as well as sex.

5. Conclusions

This observational study followed two groups of calves fed on an AMF to assess their health, feeding patterns and social behaviours prior to, over and following the weaning period. It was found that calves preferred to consume approximately 3 L of milk three times a day. This is more than most dairy farmers reportedly feed their calves, highlighting the high level of restricted milk feeding currently being used. Female calves were found to have higher displacement indexes with more visits to the AMF than males, suggesting that single-sex groupings may be beneficial to reduce aggression around the limited resources of the AMF. Overall, calf activity had a diurnal pattern, with the highest standing times during mornings and afternoons, which may put pressure on limited resources if all calves are active during these particular time periods. In terms of social interactions, calves appeared to be socially indiscriminate, not having preferred feeding partners. However, the levels of social prominence, influence, displacements and cross sucking all increased over the weaning period, possibly linked to frustrations around reducing milk availability rather than hunger, as shown by the increasing ADLG with increasing age.

Author Contributions: The study was designed by S.A.M., R.E.B., D.C.W. and N.B. The experimental work and data analysis was conducted by S.A.M. and N.B. The paper was written by S.A.M., R.E.B., D.C.W. and N.B. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: The study was conducted according to the guidelines of the Royal Veterinary College and approved by the Clinical Research Ethics Committee of the Royal Veterinary College (protocol code URN 2020 2014-2).

Informed Consent Statement: Informed consent was obtained from the owner of the animals used in the study.

Data Availability Statement: Data supporting the results can be requested from the corresponding author.

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

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