Learning Behaviour and Observed Feeding Patterns of Dairy Calves Group-Housed and Fed Using an Automatic Milk Feeder

by

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A Thesis
presented to
The University of Guelph

In partial fulfilment of requirements
for the degree of
Master of Science
in
Population Medicine

Guelph, Ontario, Canada

ABSTRACT

OBSERVATION OF DAIRY CALF LEARNING AND DRINKING BEHAVIOUR IN GROUP HOUSING WITH AUTOMATIC MILK FEEDERS

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This thesis is an investigation of the characteristics and behaviour of calves living in a group environment and trained to drink from an automatic milk feeder (AMF). Calves (n=147) were trained on either a solid or gated stall design associated with the AMF and behaviour was observed by video and feeder data collected for 72 h after introduction. Stall design alone did not impact how quickly calves adapted to the feeder, but when calves were stratified based on how easily they were first trained on the feeder, calves trained on the solid design explored the stall and drank 2 times sooner than calves on the gated design. Once calves learned to use the AMF, they exhibited a diurnal feeding pattern at the group level which declined during dark hours and peaked when there was human activity in the room.

AKNOWLEDGMENTS

First, I would like to thank my advisor Dr. Derek Haley for providing me with this opportunity and believing that I could accomplish anything I set my mind to and providing insightful suggestions and support throughout my research. I would also like to thank the rest of my advisory committee for all of their wisdom, advise and support. I would like to thank Dr. Trevor DeVries for challenging me to critically evaluate all of my research, his advice on study design and his enthusiasm for animal behaviour research. I would also like to thank Dr. Stephen LeBlanc for his wealth of knowledge and patience, taking the time to help me understand my statistical methods and put my thoughts together logically.

I also want to give a big thank you to William Sears for spending countless hours explaining the simple things time and time again, and trying to figure out what to do with the incredible amount of data I had to work with.

This project would not have been possible without the cooperation from all the staff at the Research and Innovation Centre-Dairy Facility in Elora. Everyone was so friendly and welcoming, it made those early weekend mornings much easier. Thank you to Joe Parkinson for allowing me to be the first researcher to drill holes in the shiny new ceiling of the calf rooms at the new dairy facility. And to Laura Wright for helping me figure out the details I didn't even realize I had not thought of, and for taking the time to answer all my emails when I had "just one more quick question".

Throughout this study I had a number of volunteers to help me collect data and wrangle calves which escaped the calf room and ran throughout the barn. I would like to thank all of you for committing to early mornings on the farm, especially on such short notice.

I would also like to thank all the graduate students I have met throughout my journey, for listening to my rants and giving me advice about research, writing and life in general! You guys have become amazing friends and I am so glad to have met each and every one of you.

Lastly, I would like to thank all my family and friends for the infinite amount of support. You have been there through the good times and the bad and without your love and encouragement I would not be where I am today.

STATEMENT OF WORK DONE

The funding for this research project was provided by the Dairy Research Cluster as well as additional funding from Dairy Farmers of Canada as well as Tier II funding from Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) obtained by Dr. Derek Haley.

The methodology of data collection for this study was discussed and developed between Tanya Wilson and Dr. Derek Haley. Dr. Stephen LeBlanc and Dr. Trevor DeVries were both involved in the development of the analysis. The behaviour scoring system used in Chapter 1 was developed by Tanya Wilson with the guidance of Dr. Derek Haley.

Data collection was performed by Tanya Wilson with the assistance of various volunteers and fellow students. Lab work, including video observation was completed by Tanya Wilson. Data cleaning and analysis was performed by Tanya Wilson with the help of William Sears and Dr. Stephen LeBlanc.

The writing of this thesis was performed by Tanya Wilson with the guidance of Dr. Derek Haley, Dr. Stephen LeBlanc and Dr. Trevor DeVries.

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AMF = automatic milk feeder

RFID = radio-frequency identification detector

Chapter 1: A review of literature on dairy calf feeding and housing and their implications for calf behaviour

INTRODUCTION

A majority of calves in the dairy industry are removed from their dam within the first 24 h of life and are fed and raised under the care of humans (Barkema *et al.*, 2015; Vasseur *et al.*, 2010). This means it becomes the responsibility of the producer to care for and feed these animals to ensure good replacement animals for the future herd.

Animal welfare is a topic that is of public interest, with issues related to calf separation and calf rearing both being of particular concern to many people (Ventura *et al.*, 2013). In a recent survey of farmer perceptions in regards to switching from manually feeding calves to using automatic milk feeders (AMF), motivations were related to decreasing labour and improving working conditions. However, a number of producers responded that they were motivated to make the switch because they wanted calves to be able to exhibit more natural behaviour, and easily be able to increase the amount of milk being fed (Medrano-Galarza *et al.*, submitted).

Research has shown benefits to housing calves in groups, if well-managed. A challenge becomes how to monitor and feed calves individually while group housing. In Quebec, between 2005-2007 no producers had adopted the use of AMF technology (Vasseur *et al.*, 2010), but a more recent survey of 670 producers across Canada in 2015 showed roughly 16% of farms had made the switch from manual feeding methods to AMF (Medrano-Galarza *et al.*, submitted). While this technology is gaining in popularity, many questions remain about their use. For example, it is unclear whether a design with solid or gated stall walls may impact calves use of the feeders, or their learning to use them.

Once calves have learned to use the feeder, there is a question of how they interact with them. In the past, calves would nurse from a dam which would facilitate the calf learning to suckle and which had control over when and how much the calf consumed. Now that calves are in the care of humans, it is the producer that has to teach the calves to drink, and dictates when and how much they consume (Vasseur *et al.*, 2010). With the introduction of AMF, roles have been somewhat reversed. After initially being taught to use the AMF, it is then up to the calf to know to approach the feeder when it is hungry. The calf becomes the primary decision maker of when it drinks and how often, with certain restrictions in place by the producer through programming of the AMF. This raises the question of how feeding patterns develop with the use of AMF. Social interactions play a role in how young calves learn to use AMF (Fujiwara *et al.*, 2014); but there are still many variables that have not been examined. Understanding more about calves' feeding patterns and environmental factors which influence calves' learning to use AMF can help to promote faster adaption to the AMF. This review will provide an analysis of different aspects of calf rearing which can impact learning, behaviour, and welfare.

SUCKING BEHAVIOUR

In a national study in the United States, 85% of farms housed calves individually (USDA, 2016), and 88% in Quebec did so (Vasseur *et al.*, 2010). Producers reported choosing to house calves this way to monitor the health of individual calves, that calves are less likely to spread disease to one another, and that cross-sucking is not a problem in individually-housed calves (Medrano-Galarza *et al.*, submitted).

On average, calves will suckle the dam anywhere from 4 to 10 times a day, with each bout lasting 7 to 10 minutes (Bøe & Havrevoll, 1993). These sucking bouts tend to peak naturally around 65 d of age and then slowly begin to decline until the natural weaning process begins around 123 d (Lidfors *et al.*, 1994). Non-nutritive sucking is still seen when calves are left with the dam, but is more common when calves are reared artificially. They will often suck on pen mates, parts of the pen or a dry teat most often after a milk meal (de Passillé *et al.*, 1993; Lidfors *et al.*, 1994). Non-nutritive sucking and/or cross-sucking are most common after a milk meal, with the motivation being the strongest 4.5 to 5 minutes after the milk meal and decreasing after 10 minutes (de Passillé *et al.*, 1992). Often non-nutritive sucking is further categorized as cross-sucking where calves will suck on other calves' body parts, which is thought to become a health problem if the same animal is often the target of the behaviour (de Passillé, 2001; Keil & Langhans, 2001). Prior to weaning, cross sucking results in inadequate milk and energy intake for calves (Jung & Lidfors, 2001; Roth *et al.*, 2008). Post weaning, cross sucking can lead to consequences such as udder deformations, mastitis and milk loss (Lidfors & Isberg, 2003). Although, more recent research found that cross sucking in heifers post weaning did not have any detrimental effects on udder health or milk production (Vaughan *et al.*, 2016)

If calves are fed milk but not allowed to suck during or after the meal, they will be highly motivated to do so, if allowed to feed by sucking, then their motivation decreases significantly (Rushen, & de Passillé, 1995). In an experiment by de Passillé and Rushen (2006) calves were allowed to feed on their dam who had previously been milked, and were then allowed to feed for only 3 minutes, which is about half as long as they would in natural suckling. An increased total duration of sucking through an increased number of sucking bouts was observed, suggesting that limited sucking time increased sucking motivation. Similar results were seen feeding calves 75% lower milk allowance than a high allowance group, and these calves showed increased sucking and butting behaviour towards a dry teat provided after the meal (Rushen & de Passillé, 1995). Jung and Lidfors (2001) suggested that non-nutritive sucking and butting towards the udder may be a natural signal to the dam that the calf is still hungry and to increase milk production. Depending on the method used to feed the calves it can increase or decrease their motivation to suck.

Jensen & Budde (2006) compared calves fed 6 L/d by bucket to those fed 6 L/d via teat and collected data on feeding behaviour as well as cross-sucking. Calves fed from a teat spent more time ingesting milk and spent significantly less time sucking on other calves or fixtures in their pen compared to calves fed from a bucket.

The availability of milk has a large influence on sucking motivation, especially because calves suck most after a milk meal (de Passillé *et al.*, 1992). Calves left with the dam will spend longer periods sucking if the dam has been milked and does not have a full udder (de Passillé and Rushen, 2006). The same results have been seen in calves that are artificially reared and fed by teat or bucket; those on a lower milk allowance will show more non-nutritive or cross-sucking compared to those on a high milk allowance (Jung & Lidfors, 2001). When calves are allowed to suckle their milk, but at a slower milk flow rate than usual, calves will take longer to consume their milk and there is less non-nutritive sucking seen after the meal has been consumed (Haley *et al.*, 1998; Jung & Lidfors, 2001; Loberg & Lidfors, 2001; Jensen & Holm, 2003). For example, Haley *et al.* (1998) compared milk flow rates of 1.40 L/min, 0.70 L/min and 0.3 L/min. This could mean that even calves on a lower milk allowance may decrease the amount of non-nutritive sucking if the milk flow rate were adjusted so that they took longer to consume their milk.

The presence of other calves or the dams' udder may act as external stimuli which promote or increase sucking motivation (de Passillé & Rushen, 1997). Calves in groups will show increased cross-sucking behaviour compared to pair housed calves fed via bucket, even when fed the same 6 L/d volume of milk (Jensen & Budde, 2006). Roth *et al.* (2009) observed that calves left with the dam did not perform cross-sucking behaviour; they did not examine nutritive versus non-nutritive sucking.

The evidence suggests that, of the factors examined, the taste of milk has the most influence on sucking motivation. Water will also elicit sucking behaviour, however, the response is of shorter duration than when calves are given milk (de Passillé *et al.*, 1993). Even a small amount of milk is enough to increase sucking motivation. If calves are provided with only 30mL of milk they will show more non-nutritive sucking than calves provided with 2 L of milk (de Passillé *et al.*, 1997). Researchers initially determined that milk was a strong cause of sucking motivation (de Passillé *et al.*, 1992), however, in later research it was narrowed down to be the lactose component in in the milk which had the greatest effect (de Passillé & Rushen, 2006b). As the concentration of lactose was increased, the magnitude of the behavioural response also increased. Other components of milk, such as casein, fat and whey protein were not found to have the same effect.

Performance of sucking behaviour may help to decrease stress and hunger for a young calf. Lupoli *et al.* (2001) found that compared to calves fed by bucket, calves that were allowed suckle their milk had higher concentrations of oxytocin and decreased cortisol in their blood after feeding. Oxytocin is a hormone known to have calming effects, while cortisol is a stress hormone (Squires, 2010; Squires, 2010b). When calves are prevented from sucking, they have been seen to show more abnormal behaviour such as licking, butting and biting, which could be seen as compensatory oral behaviours (Loberg & Lidfors, 2001). de Passillé *et al.* (1993) showed that compared to bucket fed calves, those given a teat for 15 minutes after their meal had increased concentrations of gastrin, cholecystokinin (CCK), and insulin in their blood. The hormone CCK and gastrin are thought to be associated with satiety, therefore decreased hunger (Moran, 2000).

It is clear that the common practice of limit-feeding calves from a bucket would stimulate high motivation to perform sucking behaviour, even more so if they are group housed. This is not the sole reason producers choose to individually house calves, but it is seen as an additional benefit. However, with each of the factors that affect sucking motivation, there is a solution, whether it be feeding more milk or simply allowing an appropriate outlet such as a teat for a calf to suck.

METHODS OF FEEDING

Because there is now substantial research which indicates that how calves are fed can affect their behaviour, alternatives to bucket-feeding are becoming more common. Feeding options include leaving the calf with the dam, nurse cows, bucket feeding, teat feeding (including teat bucket, teat bottle, teat bar) as well as AMF. Feeding frequency is commonly confounded with the method of feeding.

Dairy calves are usually separated from the dam, but in some circumstances, such as organic farms in certain countries (ex. Finland), calves may be left with and reared by the dam as long as 3 to 11 weeks (Marley *et al.*, 2010). Fröberg and Lidfors (2009) compared groups of calves allowed to nurse freely from the dam to those fed by an AMF. Calves left with the dam spent more time suckling at the nipple, they were seen to ruminate more often, spent less time active, and more time lying. It was suggested that the increased lying time could be due to increased oxytocin levels attained from increased suckling time, and that calm behaviour was an indicator of good welfare. Calves in this case had most of their meals initiated by the dam, however Lidfors *et al.* (1994) found that beef calves with their dam initiated most of their meals. Perhaps this speaks to the ability of calves to adapt to automated systems where they must approach the feeder and initiate a meal. This will be discussed further below. Or perhaps there are simply differences between dairy and beef calves which have not yet been researched. Where cows still need to be milked, but there is a desire to raise calves in a more natural way, nurse cows are sometimes used (Marley *et al.*, 2010). Nurse cows are lactating but specifically designated to rear one or several calves which may or may not be their own (von Keyserlingk & Weary, 2007). This type of feeding can be beneficial as there are very low labour requirements, low cost, and if calf introduction is done correctly, most cows accept foster calves (Hudson, 1977). Calves being able to nurse from a cow provides a very natural environment as they are housed in a group setting with other calves as well as at least one mature cow (Hudson, 1977). Natural living is considered a key aspect of good animal welfare (Fraser, 2008), although, the health of calves with nurse cows versus other methods of rearing would be an interesting comparison.

The conventional method for feeding young dairy calves is from an open bucket, with 92% of calves in Quebec being fed this way (Vasseur *et al.*, 2010). Feeding calves by buck*et al*lows producers to easily track the intake of calves by measuring how much milk goes into each bucket and how much is left at the end of a meal, buckets also make for easy clean up after feeding (Jensen, 2003). Knowing intake of each individual calf is desirable for monitoring health as well as determining a proper weaning age (Jensen, 2003). Bucket feeding does raise some concern with respect to calf welfare. Appleby *et al.* (2001) compared calves for 4 weeks that were either limit-fed 10% of their body weight via bucket or fed *ad libitum* via teat, and investigated effects on calf health and behaviour. Bucket-fed calves consumed their meals in less than one minute on average, and had more diarrhea, especially in the third week. Teat-fed calves consumed 87% more milk, and weighed 2.4 times more than bucket-fed calves after two weeks. The increased intake by *ad libitum* fed calves suggests those that were limit fed are likely hungry. It should be noted that the results of this study would have been confounded by the fact that calves in the two treatment groups differed in the way they were fed as well as the amount. The quick consumption of milk meals, which was seen in this study and often with bucket fed calves, could cause the milk to enter the reticulum instead of the abomasum, it was assumed this could lead to improper digestion and diarrhea (de Passillé *et al.*, 1992; Appleby *et al.*, 2001). New research by MacPherson *et al.* (2016) found that feeding calves large (4 L) versus small (2 L) milk meals twice per day did not decrease insulin sensitivity, likely meaning it does not affect digestion to the degree previously suggested. However, this study did not measure the speed at which calves consumed the milk, nor did they measure incidence of diarrhea.

The provision of milk through a teat, or at least a dry teat after feeding is a Recommended Best Practice in the Canadian Code of Practice (NFACC, 2009). Options for teat feeding include using a bucket that has a teat attached directly, or a bucket with a tube attached to a teat. There are also two different varieties of “teat bars”, sometimes referred to as mob feeders, for group-housed calves. One has separate milk reservoir compartments for each teat in attempt to ensure each calf gets the same amount of milk. The flaw with this design is that more aggressive or dominant cows displace subordinate calves, making consistent milk intake hard to achieve. The second is a compartment shared by all teats which can reduce teat switching, but does not ensure that slower drinking calves are getting the proper amount of milk. Nielsen *et al.* (2008) compared these two teat bar designs and found that calves with the shared compartment design consumed more solid feed and suggested this may be a result of calves finishing the milk at the same time and moving to the solid feed together, an effect of social facilitation. When calves are group housed and fed using a teat bar, it does not allow for intakes of individual calves to be easily monitored, which may be a problem for sick or weak calves.

Automatic milk feeders are a newer method used for feeding dairy calves and have been gaining in popularity in recent years (Ventura *et al.*, 2010; Jorgensen *et al.*, 2017; Medrano-Galarza *et al.*, 2017). There is certainly the potential of increased amounts of cross-sucking seen in calves fed by AMF, but this is more so related to group housing in general as well as other management factors, and can often be controlled (Weber & Wechsler, 2001). The drawbacks to AMF, discussed below, are outweighed by the benefits they offer including: more natural feeding routines, ease of weaning, and disease detection. Meal plans specific to calves can be programmed on AMF that supply calves with specific portions and concentrations of whole milk or milk replacer spread throughout the day, eliminating large meals or gorging, and promoting a more natural feeding regime (Lely, 2016; Milk Products Inc., 2011). Automatic milk feeders can also be programmed to slowly wean calves off milk which has been proven much less detrimental than abrupt weaning (Jensen, 2006). The program can also be designed to wean individual calves as they reach certain ages, ensuring calves are not being weaned too young. As an example, calves that were fed 8 L twice per day via bottle were weaned at either 6 or 8 weeks of age. Calves weaned younger had consumed one third of the amount of solid feed compared to calves weaned at 8 weeks, and average daily gain the week of weaning decreased by 44% in younger calves compared to 12% in the older calves (Eckert *et al.*, 2015). There are also various gradual weaning options made easy by the computerized feeder, they include decreasing the number of milk portions per calf per day, or decreasing the amount of milk per portion (Jensen, 2006).

There are AMF which can feed calves housed in individual pens, but the AMF referred to in this paper require calves to be housed in groups, which has its own concerns related to disease (Svensson & Liberg, 2006). There is research which has identified that the data from AMF can be used to help identify unwell calves. Svensson and Jensen (2007) looked at conditions such as arthritis, diarrhea, dull calf syndrome, fever, omphalophlebitis and respiratory disease in calves housed with automatic feeders. Calves were in groups of 5 to 10, and the authors found that drinking rate and milk intake were not associated with disease, but a decreased number of unrewarded visits to the feeder was statistically associated with a clinical status. A low milk allowance of 5.6-8.1 L/d was thought to be an explanation for these results. Unrewarded visits on a regular basis may indicate hunger, and on days when a calf is unwell it is likely to have a reduced appetite and therefore the number of visits will decrease. Similar results were found when Borderas *et al.* (2009) used calves on high and low milk allowances to look at behaviour that may be associated with illness. This study did use data collected from 4 different experiments, and 'low' fed calves were given 4 L/d in all experiments, but 'high' was either 12 L/d or *ad libitum* depending on the experiment. Calves on a high milk allowance had decreased number of feeder visits, decreased daily intake and an increase in duration of visits prior to being diagnosed as ill. Calves on a high allowance still consumed 8 L/d on average which was double that offered to low allowance calves. Borderas *et al.* (2009) suggested that the low milk allowance, and therefore hunger, may be the reason that low allowance calves showed no difference in frequency of visits or intake before or after illness was detected. Similar results were seen in a recent study by Knauer *et al.* (2017) examined the feeding behaviour of 176 sick calves against a matched control. This was an observational study performed on 10 different farms, all with AMF and providing a minimum of 7 L of milk per day. They found that calves diagnosed as sick by a study technician, drank more slowly, consumed 1.2 ± 0.6 L less than the control and had 3.1 ± 0.7 times less unrewarded visits. Changes in calf behaviour were noted up to 4 days prior to diagnosis and continued 7 to 10 days after treatment. From the results of these studies it could be inferred that if calves are fed high milk allowances, AMF data could be used to detect early or subtle illness in calves.

There are many choices for producers when it comes to feeding calves. Often the selection is based on factors such as the amount of milk being fed to the calves or the type of housing. There are trade offs to each feeding method but some, such as bucket feeding, have greater implications for animal welfare. Automatic feeders have the potential to satisfy animal welfare in that they allow calves to suckle their milk, feed more frequently in smaller meals, and it becomes easier to then feed calves at a higher milk allowance.

FEEDING AMOUNT

Calves are typically fed milk at 10% of their body weight, divided into two meals per day (Appleby *et al.*, 2001; Vasseur *et al.*, 2010; Lely, 2016; Medrano-Galarza *et al.*, 2017). In a recent survey by Medrano-Galarza *et al.* (submitted) producers revealed that they would like to feed a higher milk allowance to calves, but for those feeding manually it would mean increasing frequency of feeding and therefore an increase in labour. This was one of the primary motivations for switching to AMF systems; it easily allowed more meals per day, and therefore more milk, for the same amount of labour. The computer program also keeps track of how much each calf is allowed, particularly useful around weaning, and eliminating the need to manually keep track of each calf's stage of milk feeding. While the Canadian Code of Practice states that calves must receive enough milk or milk replacer "to maintain health, growth and vigor", there is no minimum required volume (NFACC, 2009). It is suggested as a 'best practice' to offer calves a minimum of 20% of their body weight, or approximately 8 L/d until at least 28 days of age.

There is a large amount of variability in the amount of milk producers are feeding (OMAFRA, 2012; Vasseur *et al.*, 2010). This might be due to beliefs or tradition, economic reasons or perhaps a lack of knowledge regarding why it is best to feed calves one amount versus another. A survey of Quebec dairy farmers showed that more than 50% of farms feed 10 to 12% of the calf's body weight in milk (Vasseur *et al.*, 2010). Researchers have shown that feeding calves more milk than the conventional 10% of their body weight is beneficial, though there is still dispute by those who believe that giving calves too much milk can have negative consequences (Jasper & Weary, 2002; Borderas *et al.*, 2009; de Passillé *et al.*, 2014).

Borderas *et al.* (2009) compared the amount of milk fed to calves on AMF in two experiments. In the first experiment calves on a low milk allowance of 4 L/d were compared to calves fed *ad libitum*; calves on the 4 L milk allowance were then compared to calves on a high milk allowance of 12 L/d in a second experiment. When they compared the results of both experiments, calves allowed high milk volumes (12 L or *ad lib*) had significantly higher milk intakes in the first two weeks than calves on a low milk allowance, and their overall average daily gain was greater. Calves fed 4 L/d had 90% of their visits to the feeder unrewarded, showing that these calves were hungry and seeking more milk. This effect has also been seen across different feeding methods. Calves fed 10% of their body weight by bucket a conventional consumed 176 kg of milk before weaning compared to 316 kg consumed by calves fed *ad libitum* (Jasper & Weary, 2002). Calves fed *ad libitum* only consumed 16% as much calf starter and 17% as much hay compared to calves fed 10% of their body weight, but the ad libitum calves did maintain a higher average body weight throughout the experiment, finishing the experiment 8 kg heavier on average than limit fed calves. A similar study which allowed calves 12 L/d from teat buckets found more than half the 130 calves drank more than 4.9 L, just two days after birth (de Passillé *et al.*, 2014). These calves had an average daily gain ranging from 0.07 to 1.18 kg/d, unfortunately starter intake was not measured in this study. This is evidence that feeding calves just 10% of their body weight is insufficient, leaves calves hungry and decreases their welfare.

Borderas *et al.* (2009) also suggested that limit feeding calves under 3 weeks of age decreases their welfare due to hunger, because they do not yet have a rumen to digest solid feed and cannot compensate their lack of nutrients by consuming concentrate. Increased concentrate consumption by older limit-fed calves before weaning, as was the case in that study, can likely be explained as a means of trying to eliminate their hunger. The increase in solid feed intake is sometimes referred to as a benefit of limit feeding calves. However, Jasper and Weary (2002) observed that limit-fed calves consumed more starter before weaning, but that there was no difference compared to an *ad libitum* milk-fed group post-weaning. The idea that limit feeding calves so they will consume more starter becomes lost post weaning as they eventually end up consuming similar amounts anyway. The calves fed higher amounts of milk maintain a weight and growth advantage over limit fed calves.

There is a perception that an increased incidence of diarrhea is associated with feeding calves increased amounts of milk, but there is no scientific evidence to support this. However, there are studies which show no difference in the amount of diarrhea seen in limit fed and high milk fed calves (Jasper & Weary, 2002). Perhaps this idea evolved from calves having increased diarrhea when meal fed more milk via bucket, because bucket fed calves may be at higher risk than calves fed via teat, especially when ingesting large amounts of milk within a short time frame (Appleby *et al.*, 2001). It was thought that this could affect glucose sensitivity and therefore impair digestion (Bach *et al.*, 2013). This has recently been disputed; MacPherson *et al.* (2016) experimented using similar methods comparing individually housed calves fed 4 L/d and 8 L/d and found that the amount of milk did not affect glucose sensitivity.

Overall there are far more proven benefits to feeding young calves higher volumes of milk, and any negative consequences thought to be associated with higher milk volumes can often be linked to other management factors. It costs more to feed calves a higher volume of milk which is a disadvantage to producers. Terré *et al.* (2009) found that calves allowed a higher milk allowance (up to 7 L/d) had their first breeding earlier and had increased milk yield compared to calves given just 4 L/d. This study did not find these results to be significant, but mentioned that their analysis may have been lacking power. These results are consistent with other studies which found numerical but not significant differences for age at first calving (Morrison *et al.*, 2009; Raeth-Knight *et al.*, 2009).

For producers that choose to feed higher milk volumes to their calves, it is harder to do so in a group environment. For methods such as bucket feeding, or mob feeders, dominant calves can displace subordinate calves and then issues of calves gorging or not drinking enough becomes an issue; hence why automatic feeders are a beneficial option, calves are monitored and are only allowed their own milk allotment.

GROUP HOUSING AND AUTOMATIC MILK FEEDERS

A survey in Quebec showed that 88% of farms house unweaned calves individually (Vasseur *et al.*, 2010). Evidence since then suggests that more farms moving towards group or pair housing (Jorgensen *et al.*, 2017; Medrano-Galarza *et al.*, 2017). There are various reasons why a producer may choose to group house calves, however if an AMF is chosen as a means of feeding, there is the option of a calf rail which feeds calves in individual pens, but more often calves will be group housed (Milk Products Inc., 2011). Depending on the type of feeder, as well as area of the pen, one AMF is promoted as being able to support 25-30 calves, though there is no available data to support this (Milk Products Inc., 2011).

Group housing has proven beneficial in social and cognitive development. Costa *et al.* (2014) compared individually housed calves to those in complex social housing (with other calves and cows), and found that those in the latter treatment group were more likely to consume a novel food. It has also been reported that calves housed in pairs or groups tend to consume more starter during the weaning period, possibly due to social facilitation (Chua *et al.*, 2002; de Paula Vieira *et al.*, 2010; Miller-Cushon & DeVries, 2016). Though this is not always the case; Terré *et al.* (2006) found no difference in the amount of starter intake between individually housed calves and those in groups of five, but this could be attributed to a difference in milk feeding programs, as calves were purchased for the study at 12 days of age, it is possible that different feeding methods or amounts in those first 12 days could have impacted results in some way. There is other evidence that supports that calves housed in pairs or groups are less sensitive to changes in environment and social structure than individually housed calves (de Paula Vieira *et al.*, 2010; de Paula Vieira *et al.*, 2012) and perform better at learning tasks and cognitive tests (Gaillard *et al.*, 2014). Calves moved to groups after being in pairs for 56 days had a shorter latency to visit the AMF than individually housed calves, had higher weight gains, and higher starter intake after mixing (de Paula Vieira *et al.*, 2010). It was suggested that paired calves had an advantage because they have social experience and may learn how to use an automatic feeder from observing other calves, while those housed individually need to learn how to socialize as well as to use the feeder. In a similar trial, calves of individual, paired and two types of group housing (3 young calves or 2 young and one older calf) were tested at 65 days of age to compare behavioural reactions to a novel environment and social stimuli (de Paula Vieira *et al.*, 2012). These tests were performed in a test arena for 15 min without their group mates, and the social test was done with a calf they had never encountered before. Calves from individual pens were more active in the arena, they explored the novel environment for 62 s/test longer, spent 79 s/test less time standing. The authors suggested this was due to these calves having more anxiety, or the large space of the arena being more rewarding to them. They were also more reactive to unfamiliar calves, it took them 91 s/test longer to initiate contact with another calf, but once they did they spent 51 s/test longer interacting with new calves and kicked twice as much per test compared to those which came from paired housing. These results suggest that calves coming from individual housing might have a harder time adapting to a new environment. This could make it more difficult for these animals to adapt to group housing when they are older, or to enter a novel environment such as a milking parlour.

Given the choice, calves will choose to feed with and to lay with a familiar social partner rather than alone (Færevik *et al.*, 2007; Miller-Cushon & DeVries, 2016). Not only do calves prefer to be with social partners, but they also show increased play behaviour compared to calves in individual pens (Valnikova *et al.*, 2015). Individually housed calves tend to play more and be more active in a test arena but this is thought to be an effect from being exposed to a large space compared to their individual pens which are usually much smaller and do not allow space to run (de Paula Vieira *et al.*, 2012; Valnikova *et al.*, 2015). Play behaviour has long been thought of as an indicator of good welfare, thus implying that group pens offer better welfare in terms of space for play as well as providing social companionship. Paired and grouped calves tend to vocalize a lot when separated, an indicator of stress, and implying calves would prefer to be together (de Paula Vieira *et al.*, 2012).

Group housing is sometimes criticized because of concern that it may promote the spread of disease, and that it is harder to detect diseased calves early in groups. In a survey of 122 Swedish dairy farms, group-housed calves were more often reported having diarrhea and had more severe diarrhea than individually-housed calves, and had increased odds of respiratory disease (Svensson *et al.*, 2003; Svensson & Liberg 2006). There is certainly more opportunity for disease transmission between calves in group pens, and this is multifactorial and related to things like colostrum intake, group size and management style; meaning that some proportion of disease can be avoided through management. Jorgensen *et al.* (2017) evaluated the health of over 10,000 calves housed in groups with AMF on 38 farms to determine risk factors for illness. They found that season affected all health outcomes, and that increased bacterial counts in the milk replacer, as well as lack of positive pressure ventilation was associated with fever. This indicates that with proper cleaning of equipment and proper ventilation could likely reduce incidence of illness. They did find that less space per calf was associated with poor ear and eye conditions, and larger groups were associated with poor nasal conditions; all of these could be due to group size and not necessarily the AMF itself. When Engelbrecht Pedersen *et al.* (2009) introduced calves to a group pen continuously versus an ‘all-in-all-out’ system (where no new calves are added to an established group), there were significant effects on disease and weight gain. When calves reached 3 weeks of age, a comparison of stable (“all-in-all-out”) and dynamic groups was done on 6 different farms. Calves were either moved as a group of six together into one empty pen for six weeks, or were moved into an established group pen one at a time, where they replaced 9-week-old calves to form a group of 6. Though there was no mention in this paper of who performed the health checks on the calves, researchers found that in dynamic groups 46% and 43% of calves were affected by diarrhea and respiratory disease (respectively) compared to only 18% and 20% in stable groups. Dynamic groups also had a significantly lower (60 g/d) daily weight gain. Age differences among calves in dynamic groups being stressful and a longer interval between pen cleanings were suggested for these results. Group size is also a key factor to consider when trying to reduce the incidence of disease in group pens. Svensson and Liberg (2006) included 9 farms in a field trial where calves were moved to group pens at 12 days old on average. Calves in larger groups (12-18 calves) had respiratory disease at a ratio 1.4 times greater than calves in small groups (6-9 calves) and had a 40 g/d lesser growth rate. The results from this study were not overwhelmingly convincing, especially since large and small groups were housed in adjacent pens in the same barn. It was suggested that this could bias the results towards the null hypothesis, underestimating the difference between groups, but no explanation was provided as to why this might be the case.

Competition between calves for time at the feeder is also a factor which may inhibit producers from using AMF. As seen by Borderas *et al.* (2009), calves ages 1 to 21 days, will on average visit and occupy the feeder 24 times per day when they are limit fed compared to just 9 visits for *ad libitum* calves, creating more competition for the feeder. A study by von Keyserlingk *et al.* (2004) showed that when one teat was available for three calves, there were more competitive displacements than when there were four teats available, and that with the higher ratio, calves spent more time at the feeder and less competitive behaviour was observed. Therefore, by keeping a smaller group size and/or adding more teats to the pen, competition can be minimized. This has an effect similar to increasing milk allowance for grouped calves, because there will be less occupancy of the feeder with unrewarded visits and therefore less competition (Borderas *et al.*, 2009; Jensen & Holm, 2003; Jensen, 2004).

Other than group size, group composition is also important. Keeping calves of similar ages (within 24 d) together in a group can reduce competition compared to groups with a wide range (within 64 d) of ages (Færevik *et al.*, 2010). This could be related to life experience of the calf, or perhaps size. It was seen in one study that mixing smaller breeds such as Jerseys with Holsteins put the smaller breed at increased risk for displacement from the feeder (Jensen, 2004).

There are challenges associated with using an AMF and housing calves in groups, but these can be managed. As we continue to learn more about how calves interact with the AMF and learn to use them, strategies to cope with competition and disease will become more apparent.

FEEDING STALL DESIGN

One challenge is the ability of calves to adapt to the AMF. Studies have documented a decline in milk intake within the first days of introduction to the feeder, and many calves require a great deal of training (Jensen, 2007; Fujiwara *et al.*, 2014). When dairy calves were left with the dam, Fröberg and Lidfors (2009) found that most meals were initiated by the dam. This may help to explain why some calves take a while to learn to use the feeders. With conventional feeding methods calves have not been responsible for dictating when and how often they feed. The dam or, more likely in the case of dairy calves, the producer, approached the calf at meal time, and the amount of milk available was the amount they drank. Using an AMF, calves become responsible for when they feed, how often they feed, and to some degree how much they consume. Learning theory again becomes relevant when discussing factors that may be associated with calves adapting to using the AMF. The effect of stall design on learning comes into play from the perspective of calves being social animals. Solid sides and visual isolation when in the feeder may be an aversive stimulus (Gleitman *et al.*, 2011). It would make sense if calves were more hesitant to enter a feeder of solid sides compared to a design that still allowed visual contact with other calves.

Fujiwara *et al.* (2014) studied various factors which may be associated with calves adapting to feeders. They introduced calves from single to pens with 0-8 calves at an age of 5-6 days and gave them one training session on the feeder, with subsequent training sessions given until the calf voluntarily consumed a minimum of 2 L per day. By this protocol, only 27% of calves drank voluntarily from the feeder within the first 24 h and there was a consistent decline in milk intake in the first few days following introduction to the group pen. The authors stated this was from a delay entering the feeder, and not due to difficulty using the teat once the calf was in the feeder. Calves were retrained on the AMF each morning and afternoon if they had not consumed 1L of milk on their own. Similarly, calves introduced to a group pen at 6 days of age needed repeat training sessions (if they drank less than half its allowance within 12 h) on 2 days, in contrast to 14-day-old calves, which needed only one day of training (Jensen, 2007). It was also noted that as group size increased, the calves became more likely to need additional guidance to the feeder. Age at introduction and group size account for some of the variation in the time for calves to learn to use the feeder, but there may also be physical and environmental factors. Placement of the teat (whether it is on a hinge and moves or not), stall size and material, and the structure of the ground around the feeder (i.e., requiring a step-up to enter versus stall flooring being flush to the ground) can vary depending on the AMF installed (DeLaval, 2016; Lely, 2016; Urban, 2016). None of these features have been investigated as potential influences for learning and feeding behaviour of dairy calves.

There has been some research in dairy animals showing the impact that feeding barriers, or stalls, can have on their feeding behaviour (Weber & Wechsler, 2001; Endres *et al.*, 2005; DeVries & von Keyserlingk, 2006; Jensen *et al.*, 2008;) as well as similar research in other species (Nash Holmes *et al.*, 1987; Anderson *et al.*, 1999). Evidence suggests that when cattle are physically separated at the head (but still have visual contact) for feeding, it provides subordinate animals protection and increases their feeding time (Bouissou *et al.*, 19970). In pigs, the addition of a physical and visual barrier decreased aggressive behaviour and increased feeding time; similar results were found in horses (Nash Holmes *et al.*, 1987; Anderson *et al.*, 1999). This principle has also been demonstrated in dairy cows. A barrier can allow for subordinate animals to feed for longer periods as well as decrease displacements at the feed bunk (DeVries & von Keyserlingk, 2006). It should be noted that in this study, the barriers only provided physical separation making it harder for animals to displace one another, they still had visual contact. The effects of the degree of competition with type of barrier used, and how the barrier is positioned has been studied in dairy cows (Endres *et al.*, 2005; Huzzey *et al.*, 2006; O'Connell *et al.*, 2010) and calves (Weber & Wechsler, 2001; Jensen *et al.*, 2008).

Two studies in adult Holstein cows compared feeding behaviour and aggressive displacements between two feed bunk designs (Endres *et al.*, 2005; O'Connell *et al.*, 2010). A headlock design which provides more of a barrier between cows had fewer displacements and allowed submissive cows to feed for longer periods, especially during peak hours, compared to a post and rail design. Similarly, Huzzey *et al.* (2006) found fewer displacements with a headlock compared to post and rail design but did not find it to affect feeding time. These findings suggest that separating adjacent cows can help to reduce competition at the feed bunk. It can be noted that the focus of this research was on competition between animals, and not related to how these barriers may influence feeding behaviour at/around the feed bunk, independent of competition.

Similar results have been studied in calves. Jensen *et al.* (2008) found that the presence of a barrier (compared to no barrier) reduced competition for the teat in group-housed calves, and that longer barriers were superior to shorter ones for reducing displacements, but interestingly they found no effect on the amount of time spent drinking per visit or per day. Weber and Wechsler (2001) compared groups of 15 calves in regular feeding stalls to those with a rear gate which would close behind the calf when it entered the feeder. With the rear gate present, there were fewer competitive displacements from the feeder, and calves tended to remain in the feeder longer, performing more non-nutritive sucking thus decreasing the amount of cross-sucking in the group.

The impact of barrier design has been extensively researched in regards to competition and displacement, however there is very little known on how it may impact learning behaviour, in dairy calves. Calves previously housed in pairs perform better at cognitive tests (Gaillard *et al.*, 2014) and learn to use the feeder at an accelerated rate when moved to group pens compared to calves that had previously been housed individually. Calves are often seen to feed together (Costa *et al.*, 2014; Miller-Cushon & DeVries, 2016); from this it could be hypothesized that a stall design which allows calves to see other calves in the feeder may improve the learning process for younger calves. Calves may be more inclined to approach the feeder if they have seen other calves using it.

FEEDING BEHAVIOUR AND FEEDING PATTERNS

It is interesting to note the components of learning theory which may be involved in calves learning to use the AMF. Calves watching how others behave (or interact with an AMF) and following their example may be an example of observational learning (Gleitman *et al.*, 2011). Perhaps some part of or the whole of the feeder itself serves as a conditioned stimulus that calves learn to associate with the milk reward. Learning to associate the teat on the feeder with the delivery of milk then becomes an example of classical conditioning (Gleitman *et al.*, 2011). Once the calf has entered the feeder, it becomes a case of operant conditioning, where the calf receives milk only when the correct response is given, in this case when they begin sucking on the nipple, and not on other areas of the feeder. Calves feeding on an AMF puts the calf in charge of their own feeding schedule. Other calves play a larger role than they would have before, because now there will be competition between calves for a resource to which access is limited, with no dam or producer to intervene. Both of these factors will affect the way calves interact with the feeder, and could inspire feeding patterns to develop, a diurnal pattern for example. Identifying patterns could help us to time other events, such as training new calves or dehorning, so that we are not interrupting feeding times and affecting intake.

A considerable amount of work has been dedicated to studying the feeding patterns of dairy cows and the role this plays in health and production (DeVries *et al.*, 2003; DeVries *et al.*, 2005; Melin *et al.*, 2005). This research has included the description of a diurnal feeding pattern that is associated with the delivery of fresh feed and that cattle tend to feed within a short time after feed delivery (DeVries *et al.*, 2003; DeVries *et al.*, 2005). The research on feeding patterns in dairy calves considers milk feeding level (Appleby *et al.*, 2001; Miller-Cushon *et al.*, 2013), the social aspect of how they are housed (Miller-Cushon *et al.*, 2016), or cross-sucking and non-nutritive sucking and not specifically feeding behaviour (Jung & Lidfors, 2001). All of these studies were performed on calves fed from a bucket or a teat, and none of them on group sizes of more than 3 calves.

In adult cows, DeVries *et al.* (2005) found that when feed was delivered more times throughout the day it allowed more equal access for all cows at the feed bunk, and that subordinate cows were displaced less often. DeVries *et al.* (2003) specifically looked at diurnal variation in feeding by dairy cows at the feed bunk and found that visits to the feed bunk were consistently greater after the delivery of fresh feed, and lower during the night and early morning. Knowing more about the feeding patterns of dairy cows has encouraged more frequent feed delivery, especially in groups where social hierarchy and competition are important. However, it is not clear that principles discovered about feeding patterns in mature dairy cows can be applied to feeding behaviour of dairy calves on AMF.

Appleby *et al.* (2001) fed calves *ad libitum* via teat bucket and found individual calves had very different feeding patterns. It was noted that calves did tend to feed immediately after fresh milk was delivered in the morning and afternoon, thus not quite mimicking an AMF. Calves were also housed individually in this study; therefore, no information can be gathered about how these feeding patterns may change in a group setting. Similarly, Miller-Cushon *et al.* (2013) found that calves fed *ad libitum* had very different feeding patterns compared to those fed 5 L of milk per day in two feedings. There was greater variability in the amount of time spent feeding and meal size when calves were fed *ad libitum*. Again, these calves were individually housed and fed via teat, therefore not reflective of a situation where calves would use an AMF. There is evidence that feeding pattern is affected in pair-housed calves compared to individually housed calves (Miller-Cushon *et al.*, 2016). Pair housed calves consumed milk in smaller and more frequent meals; they also consumed more concentrate in more frequent meals than those that were individually housed. This shows that calves are likely prompted to feed with other animals, known as social facilitation (Costa *et al.*, 2014). There are also studies which compare calves introduced to the group pen with an AMF at different ages and fed different milk portions to see how that would affect their feeding and social behaviour (Rasmussen *et al*., 2006; Jensen, 2007). Their findings are consistent in that calves trained at a later age usually perform better in the new environment.

There are a few studies which looked at calf behaviour in a group setting and fed with an AMF which determined that there were detectable changes in feeding behaviour before a calf became ill and during their illness (Svensson and Jensen, 2007; Borderas *et al.*, 2009; Knauer *et al.*, 2017). In order to determine when feeding behaviour is abnormal, what is considered normal must be established first. These studies were specifically looking at sick calves, and were more interested in amount of milk consumed, rewarded and unrewarded visits and drinking speed; none of them evaluated an overall diurnal feeding pattern.

More information is known about the feeding patterns of cows in a group setting simply because cows have traditionally been housed in a group setting more often than calves. Now that the dairy industry is beginning to move away from housing calves individually, it would be beneficial to understand feeding behaviour in a situation in which calves are group housed, and therefore facing competition. It is also interesting to note that where calves are fed via an AMF, feed delivery would not be of influence, but there is still the possibility that humans coming into the room or interacting with calves could have influence. There is no information on whether calves have any sort of diurnal feeding pattern in an artificial feeding environment. If the calves are also fed *ad libitum*, their feeding behaviour would not be influenced by a limited amount of milk, but could be influenced by meal size if that was restricted. The presence of other calves has an obvious effect on feeding behaviour, but there are also other environmental factors which could be influential. One of these includes the barrier which surrounds the feeder. Its presence, as well as the type of barrier could potentially have an impact on the behaviour of the calves in a group pen.

CONCLUSION AND THESIS OBJECTIVES

A number of researchers have shown the potential benefits of allowing calves to suck their milk from a teat, and to allow them an *ad libitum* milk allowance, and the social benefits of housing calves in groups. The introduction of proAction from the Dairy Farmers of Canada has the dairy industry taking more responsibility for animal health and welfare (Dairy Farmers of Canada, 2016). Producers are expected to meet specific requirements for their cattle to ensure animal welfare, and many producers are already taking initiative to better the care they provide for their calves.

A push to move animals into group housing brings forward new issues which need to be researched in order to provide an optimal environment for raising healthy calves efficiently. More research is needed to assess what management and environmental factors influence calves' adaption to AMF. Research is also needed to assess how calves are using the automatic feeders after initial learning. This information will help to inform equipment manufacturers and producers on how they can better design and use of AMF.

The overall objective of this thesis is to determine factors which influence dairy calves learning to use AMF and to explore whether they develop diurnal feeding patterns after learning to use them. One specific objective is to explore the stall design of automatic feeders to determine whether solid or gated style sides impact how fast calves learn to use the feeder after introduction. The hypothesis for this objective is that calves likely learn faster on a gated style because they could learn by observing older calves using the AMF. Another objective will be to look at feeding behaviour of calves at a group level to determine whether they develop a feeding pattern after they have learned to use the feeder. The hypothesis that there will be a diurnal feeding pattern and that calves will feed less during the night and more during the day, similar to patterns seen in adult cattle.

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Chapter 2: Effect of automatic milk feeder stall design on dairy calf transition to feeding and group housing

ABSTRACT

Automatic milk feeders (AMF) for young dairy calves are gaining in popularity. These feeders are thought to have benefits for calf health and welfare, and may reduce labour required for feeding. A challenge is that little is known about how calves interact with AMF. The objective of this study was to observe the effects of feeding stall design on calves learning to use the AMF. The hypothesis was that solid stalls, compared to gated stalls, would result in a longer latency to approach and feed from the AMF without assistance. A total of 147 calves (80 male and 67 female) Holstein calves were enrolled at 4 d of age and introduced to a group pen and trained on an AMF. For training, calves were allowed to suck on the trainer's fingers and guided to the teat. Calves were allocated to 1 of 2 stall designs at the pen level, depending on which treatment block they were born into: with gated stall walls (n=80 calves), or with solid stall walls (n=67 calves). For 72-h after introductory training on the AMF, data from the feeders were collected and calf behaviour was monitored by video. Outcomes measured included latency to first voluntary visit to the feeder, and to first feeding, time spent in the feeder, amount of milk consumed over the 72 h, number of retraining sessions required, and exploratory behaviour such as sniffing and licking of the feeder. Data were analyzed using mixed-effects linear regression models, or a Poisson model for the outcome of retraining. Stall design frequently interacted with difficulty of training (willingness to enter feeder and drink); for the 38% of calves that were of moderate difficulty to train on a scale of 'easy', 'moderate' or 'difficult', treatment differences were detected. These calves took 2 times longer to lick/bite at the nipple, and 2 times longer to

first voluntarily drink, and consumed less milk over 72 h. These results show that simple features of a stall can influence how quickly calves learn to use an AMF, but that the influence of stall wall design may depend on how easy calves are to train on the feeder upon introduction. For many calves, solid stalls at an AMF resulted faster in adaption than the gated stalls.

INTRODUCTION

The use of automatic milk feeders (AMF) for dairy calves is a growing trend (Vasseur *et al.*, 2010; Jorgensen *et al.*, 2017; Medrano-Galarza *et al.*, 2017). However, questions remain about how best to manage the systems to optimize calves' adaption to them, and so promote health, growth and labour efficiencies. Calves typically spend a period of time housed individually before moving to group housing with the AMF, and need to adjust to new social and physical environments.

Fujiwara *et al.* (2014) investigated whether keeping calves in pairs versus individual housing prior to introduction to the group pen, 6 d after birth, may be associated with adaption to AMF. Overall, in that study they found no difference between individually or par housed calves. However, only 27% of all calves drank voluntarily from the feeder within 24 h, and there was a general decline in milk intake for the first few days after introduction to the group pen, with only 69% of calves consuming milk on their first voluntary visit to the AMF. This adaption period, with the decreased milk intake as well as the stress of joining a new social group, could potentially put calves at risk for health issues (de Passillé *et al.*, 2014). Therefore, minimizing the time it takes for calves to adapt may help improve their welfare.

It is possible that some physical features of AMF may also have an influence on calf adaption to them. There are physical differences between the design of the automated feeders that are commercially available (Milk Products Inc, 2011; DeLaval, 2016; Lely, 2016). These include: the placement and position of the teat within the feeder and whether calves have to flip it upwards to drink or not, the construction material and size of the stall, and in some cases the feeder may be on a different level than the group pen, requiring calves to step up when entering the feeder. None of these features, to our knowledge, have been investigated to determine whether they impact calves learning to use the feeder. Commonly used stall designs include a gated style (see Figure 2.1), which permits calves visual contact with the group while they feed. Another is a solid style (see Figure 2.2) where calves are unable to see in or out of the feeder stall. Researchers have previously demonstrated that competitive behaviour in dairy calves is reduced by using longer stall wall lengths (Jensen *et al.*, 2008) as well as when using a closing gate at the rear of the feeding stall (Weber & Wechsler, 2001). We wanted to investigate to see whether type of stall would affect behaviour other than just competitive behaviour of calves, but if it might impact how quickly they adapt to this type of feeding system.

The objective of this study was to compare the influence of two different AMF stall wall designs on how quickly calves learned to use the feeder. We hypothesized that calves trained on the gated stall feeder would adapt more quickly because they are able to see other calves using the feeder.

MATERIALS AND METHODS

Animals, Housing and Feeding

Sample size was calculated to detect a difference of 6 h in latency to first voluntary feeding with a standard deviation of 2 h, with a 95% confidence interval, and 80% power (WinPepi). A difference of 6 h between groups was deemed relevant because this could make a difference in the frequency of training sessions a producer has to provide per day. To detect this difference, a sample size of 114 calves was needed, with 57 calves in each treatment group.

A total of 147 calves (80 male and 67 female) were enrolled into the study and trained on the AMF. Of those calves, data from 117, 65 male and 52 female, were used in the final data analysis. Calves were born and kept at the University of Guelph Livestock Research and Innovation Centre-Dairy Facility (Elora, ON, Canada). All animals were managed according to standard operating procedures of the facility, in accordance with guidelines set by the Canadian Council of Animal Care (CCAC, 2009) and as approved by the University of Guelph's Animal Care Committee (AUP#3477).

All calves were born in individual calving pens and given 2 meals of colostrum totalling a minimum of 4 L within 24 h of birth, the first meal being given as soon as possible after the calf was born. The maximum time between birth and first colostrum via bottle feeding was 7 h. Information on time of colostrum feeding, amount fed and quality of colostrum, as measured by a colostrometer, were recorded. All calves were administered 1.5 ml of Dystosel on the first day after birth.

Calves were housed in 1 of 4 identical calf rooms (see Figure 2.3). All calves were moved to individual calf pens within each room within 12 h of birth. Individual pens were 1.67 × 1.51 (length × width) m and bedded using wood shavings. Individual pens were located in a line adjacent to the group pen with the automatic milk feeder. Individual pens were removable and the group pen measured 9.07 × 4.98m without any individual pens in place and 9.07 × 3.30m when there were 6 individual pens along one side. Calves in individual pens were able to have visual, auditory and limited physical contact with other calves in the group pen and adjacent individual pens. While in individual pens, calves were fed 2 L of milk replacer 3 ×/d by bottle (at approximately 0700, 1300, and 1900 h), totalling 6 L/d. A ratio of 150 g milk replacer to 1 L of water was fed; the same replacer and concentration was used in the bottles and the AMF. The milk replacer (Grober, Lambridge, Ontario) contained 26% crude protein and 18% fat. Once on the AMF, calves were allowed to feed a maximum of 2 L per meal and were entitled to a new meal every 2 h, therefore allowing a maximum potential intake of 24 L per 24 h for the first 27 d on the feeder.

Introduction to the Automatic Milk Feeder

On the fourth day of life (day the calf was born as day 0) calves were moved into the group pen and walked to the AMF for training (CF 1000+ CS Combi; DeLaval Inc. Tumba, Sweden). There was one AMF station per group pen which required calves to enter and register their ear tag at the radio-frequency identification detector (RFID) to obtain a milk meal. A minimum group size of 2 was used for this study so that each calf was introduced to a pen with at least one calf who was experienced at using the AMF. A maximum group size of 16 calves was used; the mean group size when a new calf was trained on the feeder was 8.82 (SD ± 3.70). All calves were trained at 0800 h, approximately 12 h after their last meal. Calves were trained by opening the gate between the individual and group pen and leading the calf into the group area by allowing it to suck on the trainer’s fingers. All calves were trained by the same individual. Gentle pushing from behind was used if necessary. Calves were led immediately to the feeder and guided to the location of the teat and allowed to consume a meal of 2 L of milk replacer. The nipple was flipped from a position where it faced downward to a horizontal position in which milk could be consumed. The trainer would allow calves to try and flip the nipple themselves so they could learn for future feedings. Calves were kept in the feeder until they had consumed their full 2 L meal allotment, or until 15 min had passed with the calf not showing interest in, or willingness to consume, more milk. The calf was then left alone to exit the feeder on their own.

If a calf had not consumed a minimum of 2 L at each of the 6 proceeding 12 h checkpoints, barn staff would show the calf to the feeder again, following the same protocol as above. If they consumed 2 L on their own, then they were left alone and not trained on the feeder again.

Experimental Treatments

The gated stall design was constructed of steel bars and was the original feeder in the facility (see Figure 2.1). Stall dimensions were 93.98 cm in length, 36.83 cm wide (rear opening), and 83.82 cm from the ground to the top of the top rail. The solid stall design used the same feeder but was adapted to fit over the existing feeder (see Figure 2.2). It measured 124.46 cm in length, 36.83 cm wide and 96.52 cm from the ground with a 12.7cm opening from the ground to the bottom of the stall. Solid stalls were constructed from white 6.35 mm thick plastic board. The type of stall treatment was switched approximately every 2 weeks and was balanced between each of the 4 calf rooms. The stall designs remained in place until all calves being tested on that design had passed their 72 h window of observation. Eighty calves were subjected to the solid stall design, and 67 calves subjected to the gated style.

Behavioural Analysis

During their initial training on the AMF, calves were given a score describing how willingly they entered the feeder and fed. They were scored on a three-point scale as either: ‘easy’, ‘moderate’ or ‘difficult’. A calf was scored based on ease of initial entry, ease of first using the teat, and the time required until 2 L of milk replacer was consumed (or failure was declared after 15 mins). Ease of entry was based on needing little to no push from behind, or whether they needed to be pushed into the feeder and then a tie was used across the back of the feeder so the calf could not back out. Ease of use of the nipple was based on the amount of guidance needed to get the nipple into their mouth. A calf which required minimal guidance to the feeder, found the nipple with minimal assistance and consumed their milk with minimal breaks off the nipple warranted an ‘easy’ training score. A training session which required the calf to be led into the feeder as well as well as pushed from behind, had to be guided to the nipple several times and took a long time to consume 2 L warranted ‘difficult’ training score. Calves which were not one extreme or the other were scored as ‘moderate’.

Video cameras (Panasonic, SDR h85) were mounted approximately 1.5 m above, and facing the front of the AMF to record calf behaviour. Calves were marked with coloured livestock spray marker as well as a collar which was colour-coded so that calves would be easily distinguishable on camera. To be able to easily observe and identify calves during night hours, a red light was hung over the feeding area and on during dark hours of 0400 to 2100 h.

Once introduced to the AMF, continuous recording took place for the next 72 h. All behavioural observations were coded by one individual using Observer Software (version XT 12; Noldus Information Technology Wagebingen, the Netherlands). The observation window began after the calf had left the feeder for a minimum of 2 min after training. Outcome behaviours observed using the software are described in Table 2.1.

Intra-observer reliability scoring was performed using the observer software. A total of 96 h and 8 min of video was analyzed a second time. The program then compared the 2 analyses and generated a kappa, or a measure of agreement beyond chance. With a tolerance of 5 sec allowed, an overall average kappa score of 0.74 (95% CI, 0.67-0.80) was obtained. This is considered substantial agreement (Dohoo *et al.*, 2009).

Feeding Data

Feeding data were extracted from the software on the milk feeder (one feeder for 2 rooms), with both feeders controlled by a single computer (CF 1000+ CS Combi; DeLaval Inc. Tumba, Sweden). Data collection began after the calf left the feeder after initial training and included the total amount of milk consumed in 72 h, total time spent in the feeder, total time spent feeding, and the number of rewarded and unrewarded visits. Latency to first voluntary visit (time from training to calf entering the feeder and having its ear tag read) and latency to first voluntary feeding (time from training to first milk meal of any amount, where the calf entered the feeder without any assistance) were also collected from feeder data but verified with video observation.

Statistical Analyses

A total of 147 calves were trained for this study, but only 117 were used in data analysis. Calves for whom the camera had failed (n = 10), the feeder was not working (n = 18), or they did not enter the feeder on their own within 72 h (n = 1) were not included in the statistical analyses. Another calf was not included in analyses because with stall change over, it was in a block of 1 calf. In the final analysis, of the 117 calves used, 65 were male and 52 were female. A total of 10 calves were treated for minor ailments (i.e., mild diarrhea) and medications used were either Metacam, Anafen, Nuflor, Calflyte, TMS or some combination of those. The data obtained from these calves did not seem to stand out in any way and therefore they were included in analysis. Data was used for a total of 57 (34 male, 23 female) calves on the gated stall design and 60 (31 male, 29 female) calves on the solid stall design. For difficulty of training, 49 (29 female, 20 male) calves were categorized as easy, 45 (23 female, 22 male) as moderate and 23 (13 female, 10 male) as difficult. Within the easy to train calves, 23 were trained on gated-style, 26 on the solid-style; for moderate calves there were 24 on gated, 21 on solid-style; for difficult calves there were 10 on gated and 13 on solid-style.

All data were entered into an electronic spreadsheet (Microsoft® Excel 2016, Redmond, Washington, USA). All statistical analyses were performed using SAS 9.4 (SAS Institute Inc., Cary, North Carolina, USA, 2013) using calf as the unit of observation but accounting for pen-level (group) randomization with a random (room*stall*block) term in the model (Bello *et al.*, 2016).

General linear mixed models were used to evaluate associations between stall design, sex, group size and difficulty of training on the outcome variables: time from training to first voluntary stall exploration, and time to first voluntary bite at the nipple, total amount of milk consumed over 72 h, total time spent in the feeder over 72 h, total time spent drinking, latency to first visit (where the ear tag registered on the feeder) and latency to first drink (where calf first voluntarily consumed milk). Each of these outcomes was analyzed as the number of hours from when the calf left the feeder after training to the first time the event occurred. Random effects of room*stall*block were included for all of the above-mentioned outcomes. Block represents a group of calves that were tested on the same stall design within the same approximately 2-wk window and in the same room; overall there were 17 blocks of calves. Each model was first run with the variables stall design, difficulty of training sex and group size as well as all possible interactions and were reduced if they were not near significance. Significance was defined as a P-value ≤ 0.05. Group size was categorized as either small if there were 2-7 calves, or large if there were 8-16 calves. This was chosen based on previous studies which looked at group size and its association to calves learning to use the AMF (Jensen & Budde, 2006; Svensson & Liberg, 2006; Jensen, 2007) and were adapted based on the fact that the facility had a maximum group size of 16 animals per pen.

For continuous outcomes: time from training to first voluntary stall explore, first bite at nipple, amount of milk consumed over 72 h, time spent in the feeder, time spent drinking, latency to first visit and first voluntary drink, the distribution of the residuals for models with treatment as the predictor were examined graphically. These were not normal and the outcome variable was log-transformed for analysis for all variables but the amount of milk consumed over the 72 h. For all continuous variables except the total amount of time spent drinking, there was an interaction between treatment (stall design) and the difficulty of training classification. Calf sex was not a significant covariate in any model.

The number of retraining sessions was a categorical variable, to a maximum of 6 sessions, therefore a multivariable Poisson model was used. Stall design and difficulty of training were used as explanatory variables in the model, and there was no significant interaction between them. A random effect of room*stall*block was included.

RESULTS

A descriptive summary of calf-level variables can be found in Table 2.2. All of the 117 calves included in statistical analyses performed at least 1 voluntary visit and voluntary consumed milk within the 72 h observation window.

For the outcome of the time from training to first voluntary stall exploration, there was an interaction ($P = 0.046$) between the two variables stall design and difficulty of training. There was no effect of stall design among calves that were easy or difficult to train but among calves that were moderate to train there was a difference between stall design ($P < 0.001$) in the amount of time it took after training for these calves to approach and explore the stall (Figure 2.4), with those on the gated stall taking more time than those on the solid stall. Easy to train calves took on average 2.31 h and 1.50 h on the gated and solid stall design respectively. Difficult calves took on average 6.72 h and 7.41 h on the gated and solid stalls, respectively. Calves classified as moderately difficult to train took an average of 5.44 h on the gated stall versus an average of 0.80 h on the solid stall. Overall, moderately difficult calves trained on the gated-style took 6.80 times longer (95% CI, 2.38-19.42) than calves trained on the solid-style AMF.

For the time from training to first voluntary bite at the nipple, there was an interaction ($P = 0.06$) between the two variables stall design and difficulty of training. There was no effect of stall design among calves that were easy or difficult to train, but among calves that were moderately easy to train, calves on the gated-style took 2.2 times longer (95% CI 1.30-3.67) than calves on the solid-style AMF ($P = 0.0034$). Calves classified as moderately difficult to train took an average of 18.21 h on the gated stall versus an average of 8.32 h on the solid stall.

Stall design did not affect the latency to first voluntary visit to the AMF. The effect of difficulty of training was significant, but there was no interaction with stall design.

For the latency to first voluntary drink, there was an interaction ($P = 0.02$) between stall design and difficulty of training. There was no effect of stall design among calves that were easy or difficult to train, but among calves that were moderately easy to train, there was a difference ($P < 0.001$) in the amount of time it took calves to voluntarily enter and drink from the feeder after their first training session (Figure 2.5). Easy to train calves took on average 15.72 h and 14.72 h on the gated and solid stall design respectively. Difficult calves took on average 23.67 h and 23.59 h on the gated and solid stalls, respectively. Calves classified as moderately difficult to train took an average of 23.78 h on the gated stall versus an average of 11.30 h on the solid stall. Overall, moderately difficult calves on the solid-style drank voluntarily 2.1 times sooner (95% CI, 1.37-3.23) than calves on the gated-style AMF.

For the total amount of time spent in the feeder, there was an interaction (P = 0.027) between stall design and difficulty of training; however, no differences in the simple pairwise comparisons were detected. There was a significant effect of group size (P = 0.038) on the amount of time spent in the feeder. Calves trained in group size of 8-16 calves spent 1.15 times less (95% CI, 0.77-0.99) total time in the feeder than calves trained group size of 2-7 calves.

Stall design did not affect the total amount of time spent drinking from the AMF. There were no interactions with other explanatory variables.

Looking at the total amount of milk consumed in 72 h, there was an interaction (P = 0.007) between stall design and difficulty of training. There was no effect of stall design among calves that were easy or difficult to train, but among calves that were moderately easy to train, there was a difference (P = 0.05) in the total amount of milk consumed over the observation period (Figure 2.6). Calves trained on the gated-style drank 3.18L less milk than calves trained on the solid-style AMF (95% CI, -6.42-0.05). Moderately easy to train calves on the gated stall design consumed an average of 17.28 L (95% CI, 15.02-19.53) of milk within the first 72 h compared to 20.46 L (95% CI, 18.14-22.78) on the solid stall design.

Stall design did not affect the latency to first voluntary visit to the AMF. The effect of difficulty of training was significant, but there was no interaction with stall design.

Stall design did not affect the number of retraining sessions which calves received after the initial training session and within the 72-h observation period. There was an effect (P =

0.039) of sex in this model, males required 1.33 times less retraining sessions than females; there were no interactions with other variables.

DISCUSSION

In this study, we observed the exploratory behaviour of calves and their learning to use an AMF in the first 72 h after introduction. Stall design by itself did not have major effects on calves learning to use the AMF. However, when calves were categorized by how easily they entered and drank from the feeder in their initial training session, stall design showed an effect among calves of moderate difficulty of initial training. All the conditional effects of stall design favoured the solid stall design. The gated stall design did not offer any advantage in any of the outcomes we tested.

With nearly a 12.5 h difference between the two stall designs in time to first voluntary feeding in 38% of calves, this could have a real biological impact. With calves feeding voluntarily that much sooner from the solid design, it means they are able to drink when they are hungry and do not need to rely on producers returning to bring them back to the feeder. It could mean increased milk consumption earlier in life which could improve growth potential. It also means less work for the producer in terms of watching new calves and having to do subsequent training sessions after introduction. Perhaps because the rest of the group pen was constructed of the aluminum gates, calves were less interested in exploring a gated feeder because it looked similar to other surroundings. For calves on the solid sides, the plastic offers something novel for them to investigate and therefore they did so sooner. As for the nearly 8 h difference in averages seen in the groups of calves that were easy versus difficult to train, this could potentially correlate to calf vigour. Perhaps this overall ‘calf vigour’ should be assessed prior to introduction to the AMF so that calves that will not adapt well could be individually fed for longer periods.

The same effect was seen for the outcomes time to first stall exploration, time to first bite at the nipple and amount of milk consumed. Calves that were moderately difficult to train and trained on the gated style stall design took more time to approach and first explore the feeder and first lick or bite at the nipple. There was no difference between stall design within groups scored as easy or difficult. The same was true for the total amount of milk consumed, with no differences within groups scored as easy or difficult to train.

The findings of this study failed to support the hypothesis that calves trained to use the AMF with gated stall design would learn to use the feeder faster than those trained on the solid stall design. We thought that by applying learning theory, that calves may learn to use the feeder by observing each other (Costa *et al.*, 2014; Miller-Cushon & DeVries, 2016; Gleitman *et al.*, 2011). In fact, the opposite was seen in the case where calves were ranked as moderately easy to train. Perhaps easy to train calves were so eager to obtain milk that stall design did not impact the outcome, and difficult calves were so hesitant that the stall design did not have impact, they were going to take longer no matter what. For calves that were in the middle and raked as moderate, perhaps they were a bit more indecisive about the feeder, enough so that stall design made a difference in the outcome.

Another possible explanation for these findings could be related to competition. It is well known in dairy cows as well as other species, that having a barrier separating animals at a feed bunk allows for subordinate animals to feed longer (Anderson *et al.*, 1999; Endres *et al.*, 2005; DeVries & von Keyserlingk, 2006). Competitive behaviour was not measured in this study, but perhaps the solid stall design allowed calves to easily learn to use the feeder without being easily displaced by other calves. On the gated style, calves could see other calves in the pen, perhaps this visual contact made it easier for calves to displace one another, or distract one another.

All calves were enrolled in a group pen which had at least one other calf experienced at using the feeder, meaning that each calf was allowed the opportunity to “observe” an older calf using the feeder, in case this were to influence how calves were learning. Other researchers who have investigated the effect of group size on calves learning to use the feeder often found group size to have an effect. When calves are limit fed they tend to occupy the feeder for more time, creating competition (Borderas *et al.*, 2009). Smaller group sizes usually means that calves are closer in age, therefore, helping to reduce competition (Færevik *et al.*, 2010). Jensen (2007) found that calves took longer to adapt to the feeder as group size increased. This did not seem to be the case in this study as only the amount of total time spent in the feeder was effected by group size, with calves in larger groups spending overall 0.87 times less occupying the feeder compared to smaller groups.

Lidfors *et al.* (1994) found that bulls had more frequent and longer sucking bouts with their dam than heifer calves. In the current study, we had fairly equal numbers of heifers and bulls and were, therefore, able to compare sexes. The only outcome detected difference was the number of times a calf had to be retrained after introduction to the feeder. Female calves required on average 2.27 retraining sessions, where males only required 1.71 retraining sessions. It is possible that because male calves are generally larger than female calves, they may be experiencing more hunger and therefore a greater motivation to visit the feeder.

One limitation to this study was that the level of activity of calves was not monitored. de Passillé *et al.* (2014) investigated whether the level of activity in the first 4 d of life, and how much time a calf spent standing versus lying down, would impact milk intake. Those researchers found that those factors did not have an impact on milk intake, however, calves were younger than those in the current study and were also individually housed. It would have been interesting to see if level of activity in a group pen had any correlation with milk intake.

From results of this study, it does not appear that the design of the stall on the feeder has a huge impact on learning behaviour. However, this brings about the questions of what other factors associated with the feeders may influence learning, things like the flooring and entrance to the feeder and whether they are flush or made of the same material, the nipple and how some designs the calves must also learn to flip the nipple upward before drinking. These factors are not just relevant for calves, but cows as well when thinking of technologies such as robotic milking parlours. Future studies should consider these physical factors and how they could impact animal behaviour.

CONCLUSIONS

The results of this study suggest that the design of the stall (solid versus gated) at an AMF has minimal impact on dairy calves learning to use these systems. Only for those calves that were moderately easy to train was an impact of stall design observed. Among those calves, a solid stall design decreased the amount of time it takes after training for calves to first explore the stall, first lick/bite at the nipple and first voluntarily drink from the feeder. They will also consume more milk compared to those trained with gated stall sides. Stall design is only one factor that may be associated with calves learning to use automatic milk feeders, and other determinants of success of use of this technology should be quantified.

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Figure 2.1: Photo of AMF with gated sides made of steel. Photo taken at Dairy Research and Innovation Facility; Elora, Ontario.

Figure 2.2: Photo of AMF with solid sides made of plastic. Photo taken at Dairy Research and Innovation Facility; Elora, Ontario.

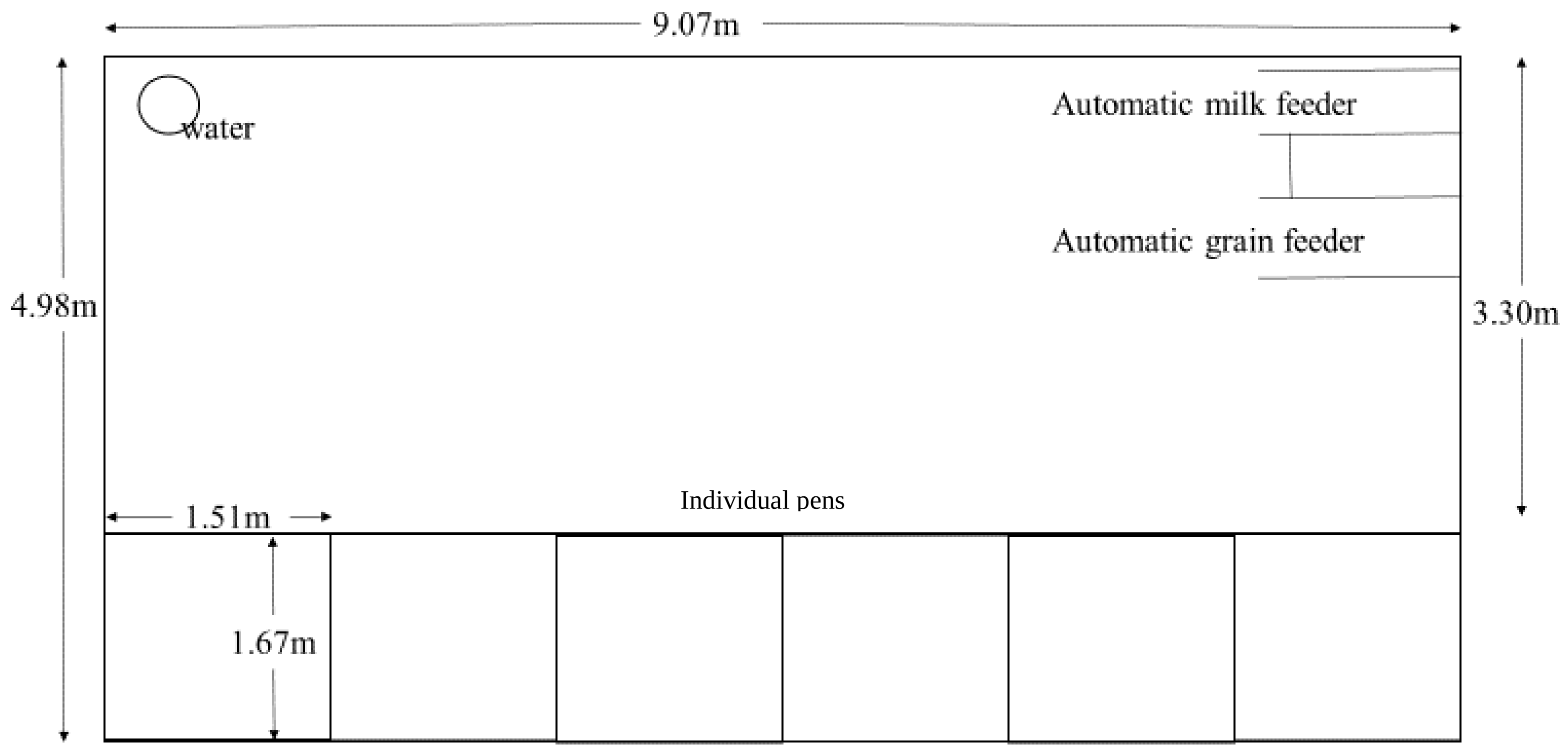

Figure 2.3: Diagram of the rooms housing calves fed by automated milk feeder, comparing solid versus gated sides on the AMF stall. Rooms 1 and 3 are identical and are mirror images of rooms 2 and 4.

Table 2.1: Descriptions of behaviours recorded from video observations; 1-2 & 7 modified from Jensen *et al.*, 1999; Endres *et al.*, 2005; Jensen *et al.*, 2008. Also recorded amount of time after training to first instance of behaviours 1, 2 and 3.

	Behaviour	*Description*
1	Time exploring stall	Total duration of time spent sniffing, licking, biting or mouthing behaviour towards the stall itself. This includes the calf being outside the feeder, or just in the feeder enough so their head is behind the ear tag reader.
2	Time sniffing	Total duration of time spent sniffing with muzzle in contact with their head at or in front of the ear tag reader (calf is almost entirely in the stall).
3	Time licking/biting	Total duration of time spent licking with the tongue or biting with teeth in contact with any part of the stall or milk feeder and long as their head is their head at or in front of the ear tag reader (calf is almost entirely in the stall).
4	Displacement	Calf is sucking but leaves the feeder as consequence of contact by another calf on any body part.
5	Assisted visit	Number of times in the 72-h observation period the calf had to be brought into the feeder by a human.
6	Approaches blocked feeder	Calf walks towards feeder as if it wants to enter, but there is another calf standing in the way so the calf either waits or walks away (recorded when calf reached 1.5m from feeder).
7	Approaches full feeder	Calf walks towards feeder as if it wants to enter, but there is another calf in the feeder so the calf either waits or walks away (recorded when calf reached 1.5m from feeder).
8	Approaches empty feeder	Calf walks towards feeder as if to enter, and feeder is not blocked or occupied so calf enters feeder or performs exploratory behaviour of the feeder (recorded when calf reached 1.5m from feeder).
9	Waiting at feeder	Calf stands at the rear of the feeder which is occupied or blocked by another calf. Calf is facing feeder, or has head in feeder and looks to have the intention of entering feeder.
10	Back out/in feeder	Calf backs out of the feeder to the point their head is behind the ear tag reader, but without completely leaving the feeder for more than 15 seconds, then enters the feeder again.
11	Approaches with another calf	There are one or more calves within a distance of 1.5m and facing towards the feeder and the subject calf approaches the feeder.
12	Approaches alone	There are no other calves within a distance of 1.5m and facing the feeder and the subject calf approaches the feeder.

Table 2.2: Descriptive summary of calf-level variables in a study of the associations of AMF stall wall design and the learning behaviour of the calves.

[1] Time from the end of initial training session to event

[2] Over the 72-h following the initial training session

Solid Stall Design (n=60 calves)					*Gated Stall Design (n=57 calves)*			
Mean	SD	Min	Max		Mean	SD	Min	Max
8.58	3.95	2.00	16.00	Number of calves in pen at training	9.07	3.43	2.00	15.00
15.13	12.99	0.38	54.45	Latency to first visit (h) [1]	17.31	14.28	0.54	69.12
18.43	13.10	3.17	54.45	Latency to first drink (h) [1]	23.70	14.13	2.88	69.12
1.43	0.82	0.06	2.00	Amount consumed at first voluntary feeding (L)	1.76	0.62	0.01	2.00
18.43	5.44	7.58	32.66	Total amount consumed over 72h (L) [2]	18.10	4.96	7.67	33.58
77.38	23.04	25.10	130.14	Time spent drinking (mins) [2]	79.22	33.21	28.21	232.53
114.62	34.81	42.47	196.83	Time spent in feeder (mins) [2]	119.84	42.36	37.43	267.92
357.01	520.44	1.24	2895.89	Latency to first stall exploration (mins) [1]	584.82	571.35	3.31	2548.86
23.07	27.89	2.59	177.02	Amount of time spent exploring stall (mins) [2]	16.86	17.84	1.61	113.39
838.28	904.49	16.61	4301.80	Latency to first sniff at nipple (mins) [1]	1035.26	867.40	8.91	4134.45
1017.58	915.51	20.35	4304.42	Latency to first lick/bite at nipple (mins) [1]	1195.97	824.68	156.91	4134.61
1.77	1.54	0	6.00	Number of retraining sessions[2]	2.04	1.49	0	5.00
6.21	5.72	0	22.03	Time spent waiting at feeder (mins) [2]	4.78	4.91	0	22.18

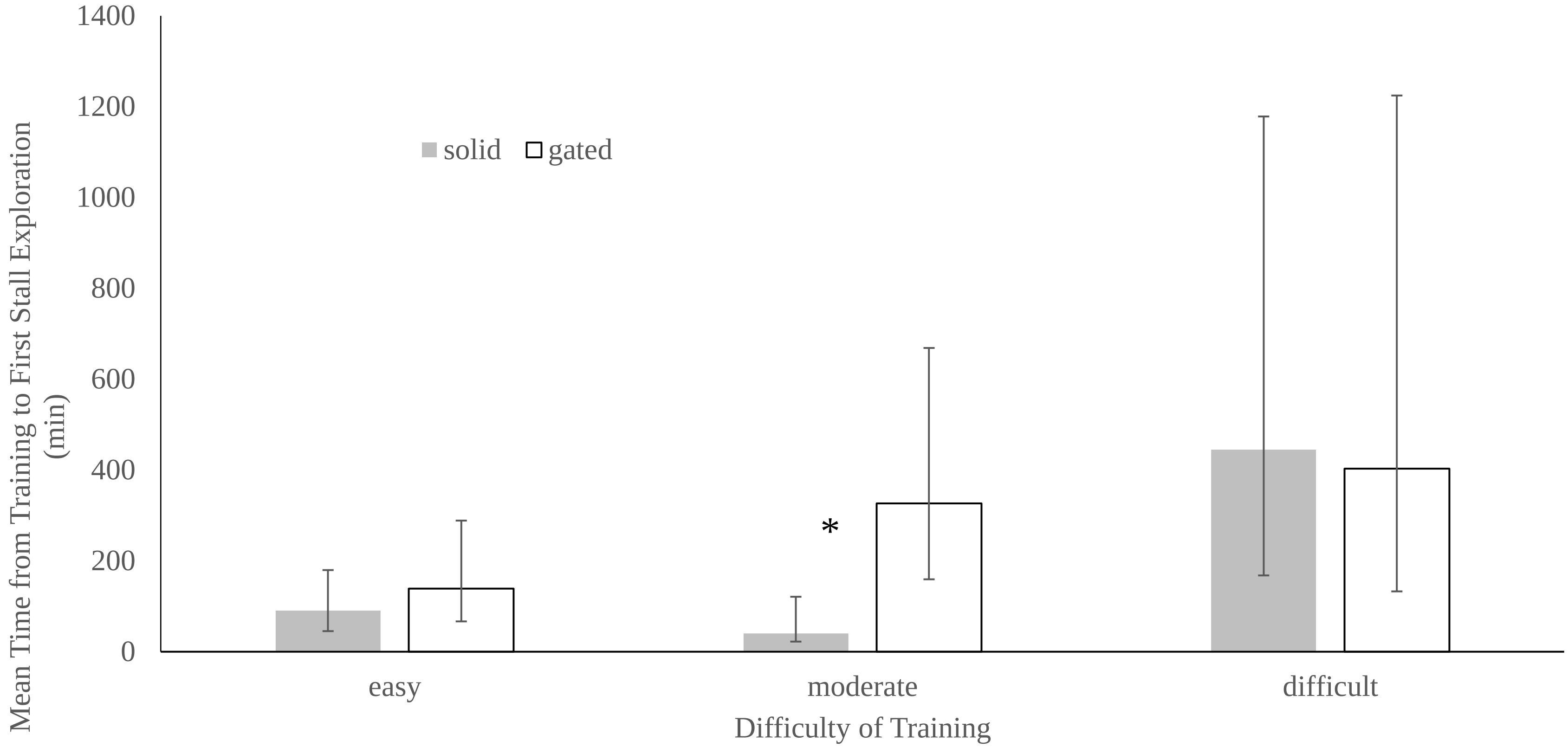

Figure 2.4: Time taken after initial training for calves to return and explore the feeder. Calves are compared within a category based on their difficulty of training score. There were no significant differences between stall design for calves within the easy and difficult scores, but there was a significant *($P<0.01$) effect of stall design for calves with a moderate training score. There were 49 calves scored as ‘easy’ (26 solid, 23 gated), 45 scored as ‘moderate’ (21 solid, 24 gated) and 23 scored as ‘difficult’ (13 solid, 10 gated). Confidence intervals are represented as the error bars in this graph.

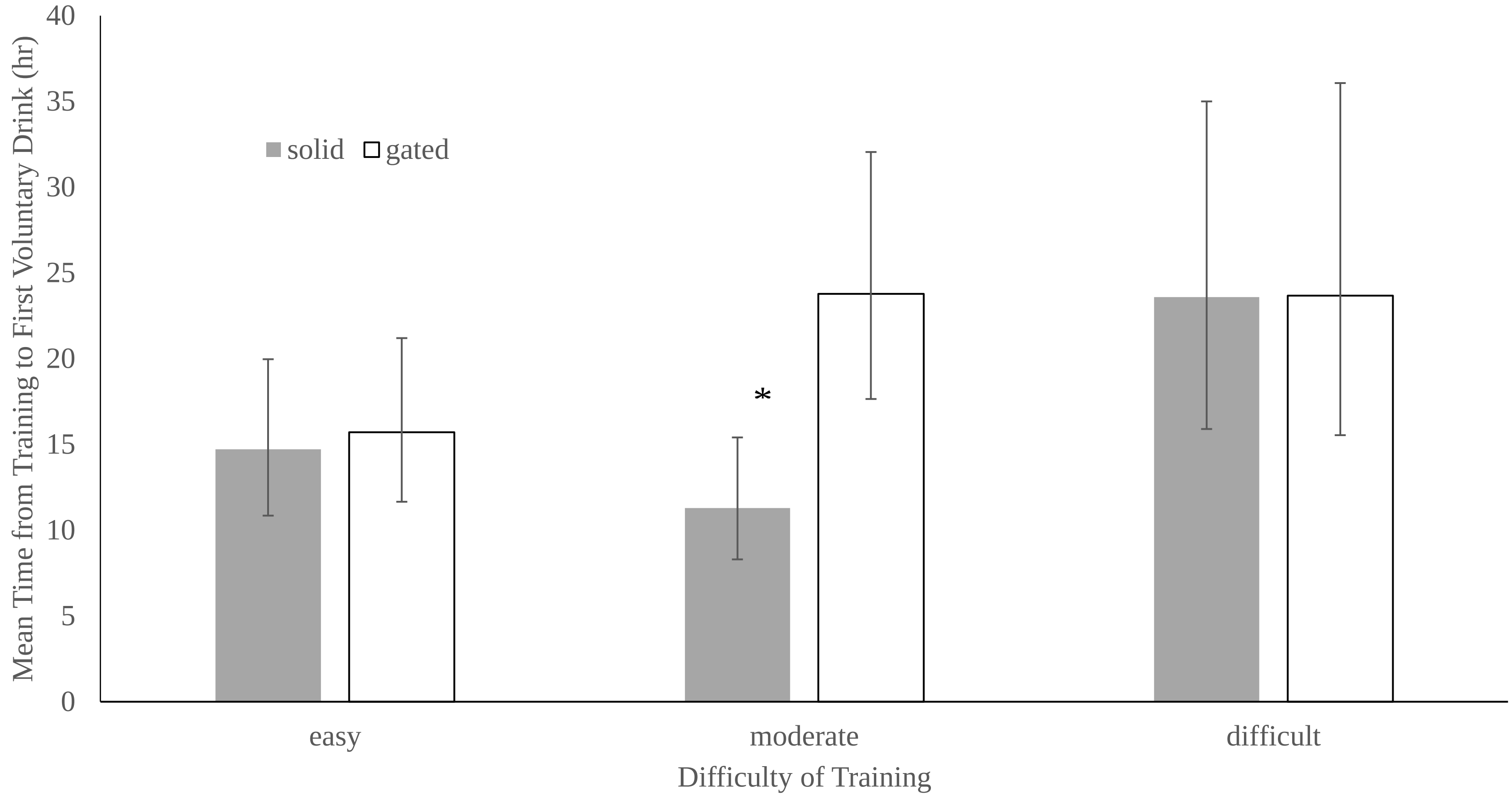

Figure 2.5: Time for calves to first voluntarily drink from the automated milk feeder after their initial training session. Calves are compared within an AMF design based on their difficulty of training score. There were no significant differences between stall design for calves within the easy and difficult scores, but there was a significant *(P<0.01) effect of stall design for calves with a moderate training score. There were 49 calves scored as ‘easy’ (26 solid, 23 gated), 45 scored as ‘moderate’ (21 solid, 24 gated) and 23 scored as ‘difficult’ (13 solid, 10 gated). Confidence intervals are represented as the error bars in this graph.

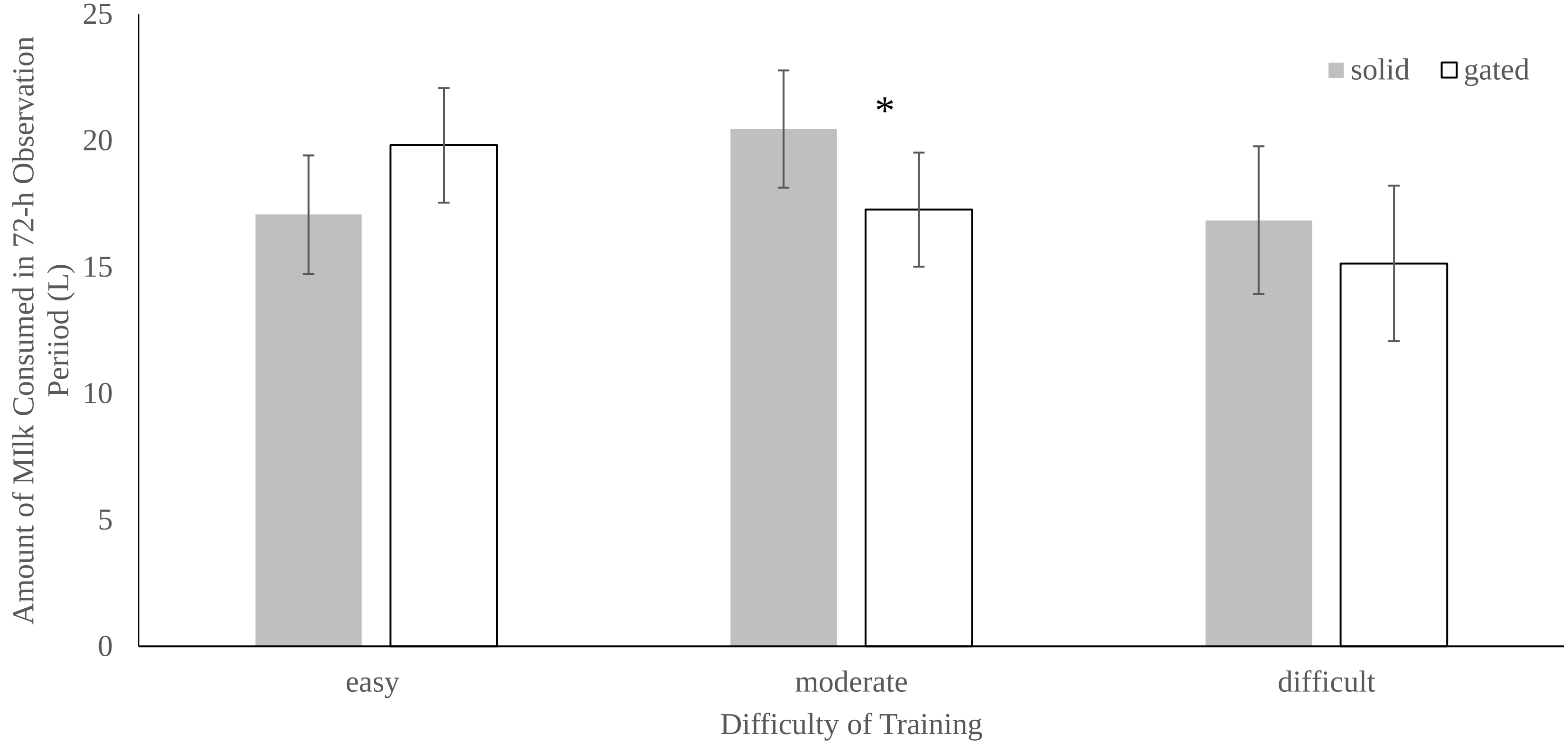

Figure 2.6: Total amount of milk consumed over the 72-h observation period, not including the 2L at training. Calves are compared within a category based on their ease of training score. There were no significant differences between stall design for calves within the easy and difficult scores, but there was a tendency *(p=0.0541) for stall design to have an effect for calves with a moderate training score. There were 49 calves scored as ‘easy’ (26 solid, 23 gated), 45 scored as ‘moderate’ (21 solid, 24 gated) and 23 scored as ‘difficult’ (13 solid, 10 gated). Confidence intervals are represented as the error bars in this graph.

Chapter 3: Characterizing the feeding patterns of calves in groups on automatic milk feeders

ABSTRACT

With the increasing use of automatic milk feeders (AMF) for dairy calves, there is still much to learn about how calves interact with them. The objective of this observational study was to describe the milk feeding pattern of calves housed in a group pen and fed using an AMF. The hypothesis was that there would be a diurnal pattern in drinking behaviour. We analyzed 49 d (over a period of 7 mo, with one wk/mo represented) obtained from two AMF machines feeding 4 group pens. A total of 123 animals, including 81 female and 42 male calves, were used for data collection. Data were analyzed using a mixed-effect logistic regression model, accounting for pen with a random effect. The amount of time the feeder was occupied as well as the proportion of total calves which visited the feeder each hour varied through the day. There were peaks in feeding behaviour when there was increased activity in the calf room between 0300 and 0400 h when lights turned on, and at times when younger, individually-housed calves were bottle fed around 0700, 1300 and 1900 h. The results of this observational study suggest that calves do develop a feeding pattern when using an AMF, but that there may be peaks due to lighting or human activity in the barn.

INTRODUCTION

There is much research on the feeding behaviour patterns of lactating cows (Melin *et al.*, 2005; DeVries *et al.*, 2003; DeVries *et al.*, 2005), but little is known on the feeding patterns of group-housed dairy calves using an AMF.

Research has focused on comparing the feeding behaviour of dairy calves fed *ad libitum* or meal-fed a restricted amount of milk (Appleby *et al.*, 2001; Miller-Cushon *et al.*, 2013); or whether calves are individually or pair housed (Miller-Cushon & DeVries, 2016). None have looked at feeding behaviour of calves housed in groups or fed using an AMF. When calves were fed *ad libitum* via teat bucket, there was a peak in meal size after fresh milk was delivered in the morning and afternoon (Appleby *et al.*, 2001). Similar results were found when calves were fed *ad libitum* or 5L per day in two meals via teat and in individual pens (Miller-Cushon *et al.*, 2013). Results from previous studies are difficult to extrapolate to group-housed calves feeding on an AMF because the stimulus of delivery of fresh milk by humans is removed. Conversely, depending on the milk allowance settings of the AMF and ease of access to the machine, calves could exhibit their preferred feeding pattern which might have a positive impact on their welfare (Fraser, 2008). There are studies which compare calves introduced to an AMF at different ages and fed different milk portions to see how that would affect their feeding and social behaviour (Rasmussen *et al*., 2006; Jensen, 2007). However, each of these studies were at the individual level and were focused on calves immediately after introduction and training, focused on differences between age groups and milk allowances.

Calves are social animals and prefer to feed together (Færevik *et al.*, 2007; Miller-Cushon & DeVries, 2016); although AMF can allow for ad libitum milk intake, only one calf can drink at a time. Maximum group sizes recommended by some feeder manufacturers can be up to 30 calves per teat (Milk Products Inc., 2011), making it important to study feeding behaviour in this environment. By understanding factors which stimulate milk drinking throughout the day, management strategies can be developed to help minimize competition, and promote more natural and healthy feeding behaviour of calves. Housing many calves with only one milk-feeding point decreases the amount of time the feeder is available and increases competition (Borderas *et al.*, 2009; Jensen & Holm, 2003; Jensen, 2004; von Keyserlingk *et al.*, 2004).

A few studies have examined calf feeding behaviour on AMF to determine whether a change in behaviour could be used to detect illness (Svensson and Jensen, 2007; Borderas *et al.*, 2009; Knauer *et al.*, 2017). However, these studies considered changes over several days in amount of milk consumed, rewarded and unrewarded visits and drinking speed; among calves that developed illness. Determining the normal calf feeding pattern could contribute to earlier detection of sick calves.

The objective of this observational study was to describe the diurnal pattern of milk feeding behaviour for group-housed calves with an AMF. We hypothesized that calves would feed less during the night and more during the day, and that the pattern would be dependant on number of calves in the pen and their age range.

MATERIALS AND METHODS

Animals, Housing and Feeding

All animals were managed according to standard operating procedures of the University of Guelph Livestock Research and Innovation Centre (Elora, ON, Canada), in accordance with guidelines set by the Canadian Council of Animal Care (CCAC, 2009) and as approved by the University of Guelph's Animal Care Committee (AUP#3477).

Data were obtained from two DeLeval calf feeders (CF 1000 CS Combi; DeLaval Inc. Tumba, Sweden). Calves were housed in four separate rooms, which were self contained within the dairy barn, with two stations on each AMF machine, such that each room had a single feeding stall with one teat. Groups were established such that one room was filled to a maximum of 16 calves, then new calves would be put into another room and each group remained together until after weaning at 56 d of age. This protocol minimized the age range in each group. All data from calves using the AMF were included and animals being treated for various ailments were not excluded unless they were removed to an individual pen and no longer feeding from the AMF. Calves were individually housed and bottle fed for the first 4 d of life in the same room in which they would join the group pen. While in individual pens, calves were given a 2-L bottle of milk replacer 3 times per d (approximately 0700, 1300, and 1900 h), totalling 6 L/d. Individual pens were 1.67 × 1.51 m and bedded using wood shavings. Individual pens were located in a line adjacent to the group pen with the AMF. Individual pens were removable and the group pen measured 9.07 × 4.98m without any individual pens in place and 9.07 × 3.30m when there were 6 individual pens along one side. Lights in the room were on automatic timers and would turn on daily at 0400 h and off at 2100 h. Staff arrived earlier for milking, but did not generally enter the calf rooms until individually housed calves were bottle fed at 0700 h.

The AMF was able to differentiate between calves using a radio-frequency identification detector (RFID) located in the ear tag of each calf. Once introduced to the AMF and group pen, calves were allowed to drink 2 L of milk every 2 h for the first 7 d on the feeder; therefore, a maximum of 24 L/d. Milk replacer was fed at a concentration of 150g for 1L of water. The milk replacer (Grober, Lambridge, Ontario) contained 26% crude protein and 18% fat. After the first 7 d on the feeder, maximum meal size was increased to 2.5 L until d 21 when it increased again to 3 L. After 27 d on the feeder, total daily limits were decreased over a 5-d period, starting at 12 L on the first day and down to 9 L on d 5. This 9 L limit continued for the next 10 d until weaning began on d 42 on the feeder. The limit over 14 d decreased from 10 L/d to 0 L/d on day 56 after introduction to the AMF.

Feeder Data

Feeder data were collected from May through November 2016. One week out of each month was used, therefore totalling 49 d worth of data. Weeks were chosen based on at least one room having a group size of 7 to 14 calves, and other occupied rooms had a minimum group size of 3 calves. This allowed us to examine data for calves housed in various group sizes. Data were collected for a total of 123 animals, including 81 female and 42 male calves.

Three measures were assessed separately to describe AMF feeding patterns: the amount of time the feeder was occupied, the number of nutritive visits to the feeder, and the proportion of calves that visited the feeder per hour.

Feeder Occupancy. We calculated the overall amount of time the automatic feeder was occupied; days were divided into 60 min intervals for each of the 24-h and the total amount of time that the feeder was occupied was calculated for each hour. The difference in AMF stall visit start and end time (recorded by the feeder) was used to sum the amount of time the feeder was occupied. This was then summed for all calves in the pen. The total time in seconds was divided by 3600 sec to get a proportion of total time the feeder was occupied.

Number of Nutritive Visits. A nutritive visit was defined as one in which milk was consumed, as opposed to non-nutritive visits where the calf was in the feeder but not drinking milk. The number of nutritive visits per calf, regardless of their duration, were totalled for the entire group for each 24-h period. A visit was considered nutritive if > 0 mL of milk was consumed. Non-nutritive visits occurred when calves entered the feeder, but had already consumed their milk allotment and were not yet eligible for more, or because they had been weaned and were no longer allowed milk. These visits could not be quantified in the and, thus, were not examined.

Proportion of Calves. The final metric considered the number calves in the room that had access to the feeder and was calculated as the proportion of those which visited the feeder in each hour of the day. If the same calf visited the feeder more than once in the same hour, it only counted once towards the total proportion.

Statistical Analyses

All statistical analyses were performed using SAS (SAS v.9.4, SAS Institute Inc., 2012). Each day of feeder data was saved as its own electronic spreadsheet (Microsoft® Excel 2016, Redmond, Washington, USA) and then combined into one file using SAS.

All models were first run with the variables hour of the day, and the number of calves in the pen, the average number of days calves had been on the feeder as well as all possible interactions and removed if the *P*-value was > 0.05. The linearity of predictor variables was assessed by offering quadratic terms for each variable in the model. Calves treated for minor ailments were assessed, but did not act as outliers and were therefore included in analyses.

A mixed linear regression model was used to determine whether there was a difference in the amount of time the feeder was occupied, between each hour of the day. This variable was analyzed at the group level. A logit transformation was done on the data and normality was checked by viewing the residual plots, histogram and quantile plot. A Tukey adjustment and anti-logit back transform was then used to obtain odds ratios. Variables hour of day and the total number of calves in the pen were included in the model as fixed effects. The effect of room was included as a random effect. A repeated measures statement was also used with the variable room*hour with a Toeplitz (toep(5)) error structure because it produced the smallest Akaike information criterion (AIC). Based on the fact that median group size was 9 calves, we stratified the data for group size ≥ 9 calves, and groups < 9 calves.

A mixed linear regression model was run to determine the number of nutritive visits between each hour of the day. This variable was analyzed at the individual calf level. A logit transformation was done on the data and normality was checked by viewing the residual plots, histogram and quantile plot. Variables hour of day, sex of the calf, number of days the calf had been on the feeder, and total number of calves in the pen were tested along with all interactions. Random effects were also included in the model, including room and the interactions between room*sex and room*sex*hour.

A mixed linear regression model was also run to determine the proportion of calves which visited the feeder each hour. This variable was analyzed at the group level. A logit transformation was done on the data and normality was checked by viewing the residual plots, histogram and quantile plot. A Tukey adjustment and anti-logit back transform was then used to obtain odds ratios. The variable hour of the day remained in the model as a fixed effect. The random effects of room as well as the room*hour interaction were included in the model.

RESULTS

There was a significant ($P < 0.001$) difference among hours of the day for the amount of time the feeder was occupied (Figure 3.1); as well as a significant effect ($P < 0.001$) of the number of calves in the pen. The odds of a calf visiting the feeder increased ($P = 0.0034$) by 6.83 (95% CI, 1.68-27.78) from 0300 to 0400 h for group sizes ≥ 9 calves. The odds increased ($P < 0.001$) by 5.01 (95% CI, 1.30-19.33) for group size < 9 calves from 0300 to 0400 h. The odds of a calf visiting the feeder also increased during times when younger, individually housed calves were bottle fed. Odds of a calf visiting the feeder increased by 2.16 (95% CI, 0.53-8.77) for groups $\geq$ 9 calves, and increased by 2.51 (95% CI, 0.65-9.66) for groups < 9 from 1200 to 1300 h; however, neither adjusted *P*-value reached significance.

For the number of nutritive visits throughout the day, the only variable which remained in the model was the number of days the calves had been on the feeder ($P < 0.001$), and its quadratic effect ($P < 0.001$). Using the estimates and intercepts, a quadratic equation was used to create Figure 3.2.

The proportion of calves which visited the feeder varied ($P < 0.001$) among hours of the day (Figure 3.3). The odds of a calf visiting the feeder increased ($P < 0.001$) by 3.44 (95% CI, 1.49-8.00) from 0300 to 0400 h. The odds also increased ($P = 0.0026$) by 1.99 (95% CI, 0.86-4.60) from 1200 to 1300 h.

DISCUSSION

Our results demonstrate that there is a pattern through the day to when calves are feeding on an AMF in a group pen. The pattern is likely influenced by cues that include lighting, human activity and calf group social dynamics.

We found a diurnal pattern in the amount of time the feeder was occupied per hour. It is not surprising to see that the feeder is occupied more often with groups $\geq$ 9 calves, and therefore we see a more pronounced pattern than in groups with < 9 calves. Looking more closely at the pattern of the larger groups, it is interesting to note that feeder use was lowest when the room would have been dark, between 2100 and 0400 h. At 0400 h, when the lights in the room came on automatically, there was a substantial increase in feeding. There would also have been activity in the barn outside of the calf rooms as adult cows were milked and fed which may have had influence. To our knowledge, no other studies have determined light to have an impact on milk feeding behaviour of dairy calves. Feeder occupancy was also higher at each of the 3 times that individually housed calves in the same room were bottle fed, thus research staff would have been entering the room at these times. Previous research has shown that calves bucket fed *ad libitum* increased milk consumption immediately after fresh milk delivery (Appleby *et al.*, 2001; Miller-Cushon *et al.*, 2013). It is possible that because calves were bottle fed by humans in their first days of life and trained to use the AMF by a human, they associated the presence of humans with milk delivery and thus increased their feeding activity. Humans would act as a stimulus to a positive reward of milk (Gleitman *et al.*, 2011). Similar results were seen by Miller-Cushon *et al*. (2013), calves fed ad libitum would exhibit peaks in feeding behaviour when restricted calves were fed. It was suggested this could be due to human activity or auditory cues from restricted fed calves. Very similar patterns can be seen when comparing Figure 3.1 and 3.3. It makes sense that the two measures would coincide, because a higher proportion of calves visiting the feeder would logically imply the feeder was occupied for more time. We assessed both to explore whether there was an indication of fewer calves visiting but spending more time in the feeder at particular times. Research in adult dairy cows has examined factors such as milking time, feed delivery and feed push ups and how they affected feeding behaviour (DeVries *et al.*, 2003; DeVries *et al.*, 2005). They found that there was an increase in feeding behaviour especially after delivery of fresh feed; a notably similar pattern between cows and calves, of decreased feeding behaviour at night and then a peak after first activity in the barn in the morning increases feeding behaviour.

Another possible component of the pattern of feeding behaviour could be social facilitation: that calves are social animals and choose to feed together (Miller-Cushon & DeVries, 2016; Chua *et al.*, 2002; de Paula Vieira *et al.*, 2010). In this case there was only one feeding station per pen, so they could not feed at the same time, but as observed in Chapter 2 at these peak hours, calves were noticed to group around the feeder together. Taken together, it seems that the presence of a person in the room can stimulate feeding, even if the person is not the source of milk for the calves. The possible direct effects of lighting need to be explored further.

To differentiate between how much time the feeder was occupied versus when the feeder was actually being used to consume milk, we looked at the number of nutritive visits. While our analysis did not show that the number of nutritive visits was affected by hour of day, it was difficult to determine the exact number of nutritive visits due to the way the AMF records visits. This was because each time a calf moved its head out of range from the RFID ear tag reader and back again, it registered as a new visit. Therefore, a calf could enter the feeder, it would register as a visit, the calf could put its head to the ground and back up again and it would appear that the calf had visited twice when in fact it never left the feeder. This happened to an even larger extent during non-nutritive visits. For this reason, non-nutritive visits could not be quantified, and the number of non-nutritive visits was likely over estimated. Nevertheless, the number of nutritive visits was associated with the number of days the calf had been on the AMF. One study found that calves fed *ad libitum*, increase duration, and rate of milk consumption, peaking between 3 to 6 weeks, and then decline (Miller-Cushon *et al.*, 2013). Similarly, beef calves left with the dam increase to a peak suckling time around 65 d and then decline (Lidfors *et al.*, 1994). Feeding behaviour in the present study is potentially confounded by the settings of the AMF machine which provided a maximum meal size and consumption per 2 h period. However, the data in Figure 3.2 show that the highest number of nutritive visits occurred before maximum milk allowance. While it is expected that calves with a decreasing milk allowance from day 27 on the

AMF would have fewer nutritive visits, that change began when calves could have consumed up to 36 L/d. This might indicate that calves seek to consume > 3 L in at least some 2 h periods. We may have seen the same pattern if calves were truly fed *ad libitum* throughout the study period, but unfortunately, we cannot conclude much in this case as we only have feeder data and do not know what was physically happening in the room. It is interesting to note that the same pattern of hour throughout the day, seen for feeder occupancy and proportion of calves to visit, was not significant for the proportion of nutritive visits. This could mean that calves are simply not visiting the feeder in the same pattern as they are drinking, or maybe they are limited by the feeding program and that affects the pattern in which they consume milk.

This study is the first to investigate patterns in feeding behaviour using AMF data. The results generate more questions on the impact of human and lighting on feeding behaviour. Future research should explore whether certain feeding behaviours (i.e., smaller, more frequent meals) are desirable for calf health and growth, and how to optimize management of groups and AMF settings to achieve these ends.

CONCLUSIONS

Dairy calves, housed in group pens with 3 to 16 calves and fed with an AMF, demonstrated a diurnal feeding pattern. Time of day had an effect on the amount of time the feeder was occupied as well as the number of calves visiting the feeder per hour. Peak times for feeder occupancy were centered around morning and evening, which coincided with the times that adjacent younger calves were bottle fed. Feeder use was lower when the room was dark. There may be opportunity to manage human interactions and lighting to optimize the efficiency and success of AMF.

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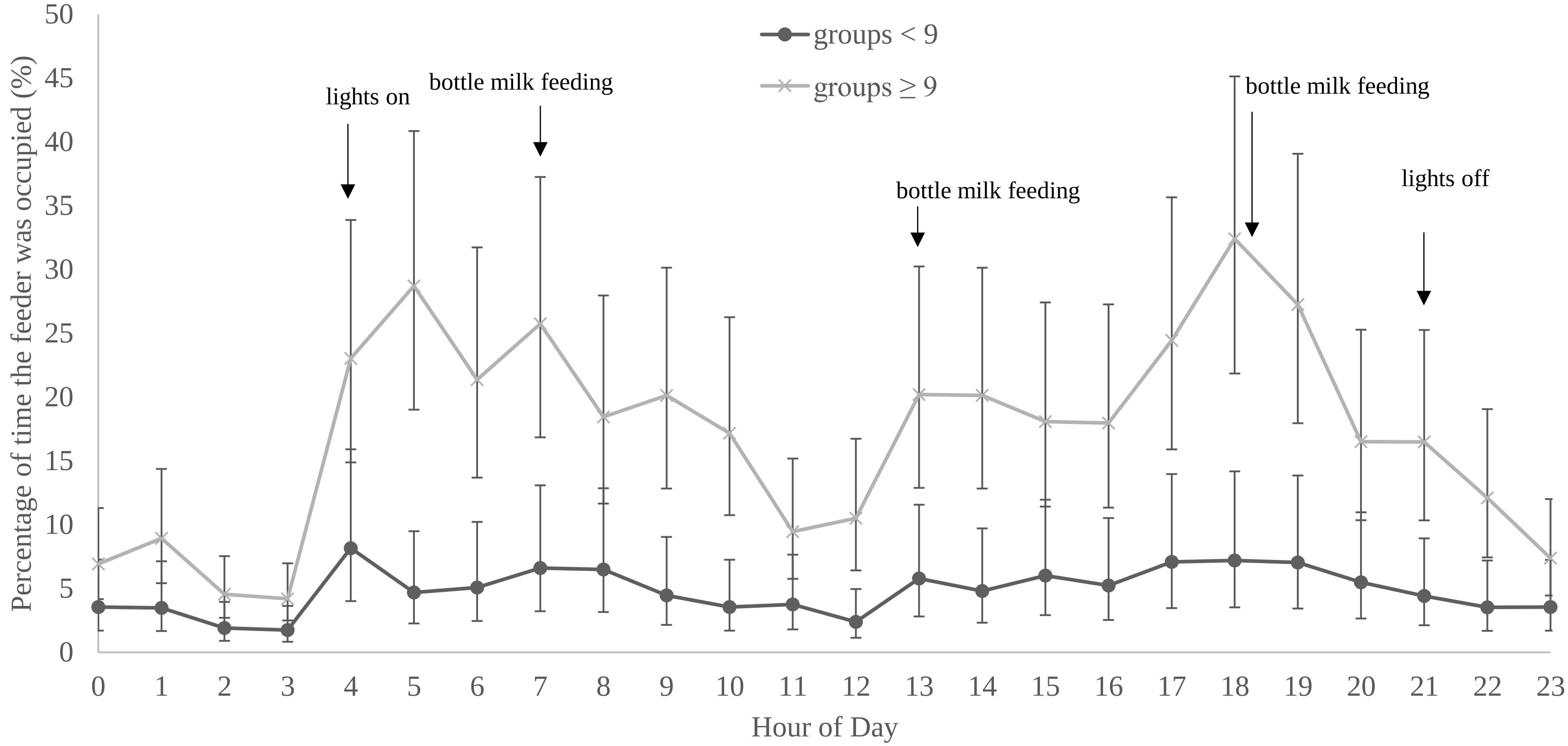

Figure 3.1: Average percentage of each hour each day, in which the automatic milk feeder was occupied by a calf. Proportion was calculated by dividing the number of seconds the feeder was occupied by 3600 seconds. This data is cumulative of 123 calves (81 female, 42 male) over a total of 49 d through a 7 month period. Calves were housed in groups of 3 to 16 calves and feeding from a single AMF. Median group size was 9 calves; therefore, this data was stratified based group size ≥9 calves, or groups <9 calves. The vertical bars represent 95% confidence intervals, those parallel to each other which do not overlap represent significantly different percentages.

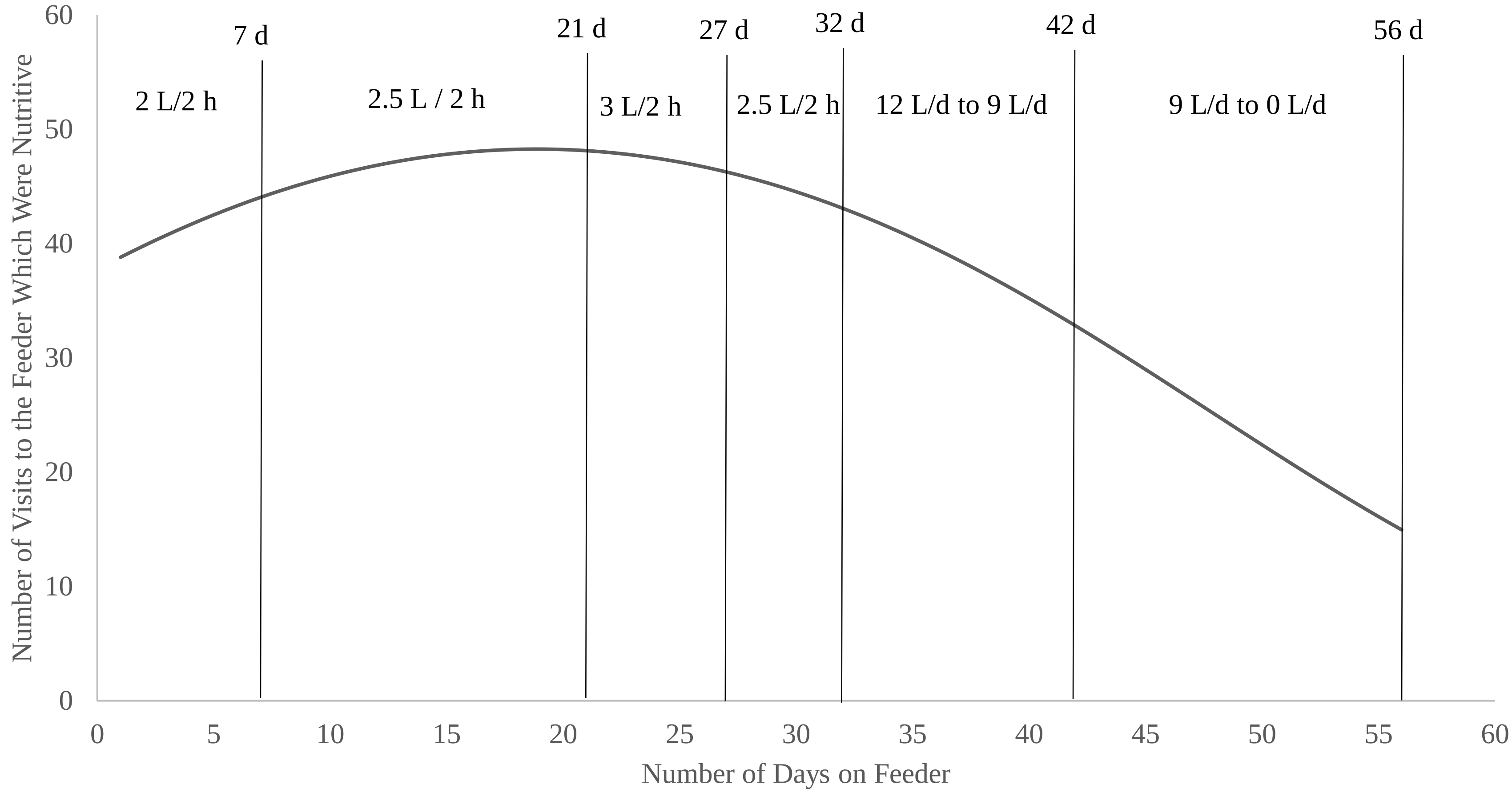

Figure 3.2: The number of visits to the automatic milk feeder which were nutritive. Calves were fully weaned on day 56. These data are cumulative of 123 calves (81 female, 42 male) over a total of 49 d through a 7 month period. Calves were housed in groups of 3 to 16 calves and feeding from a single AMF. The AMF was programmed to allow calves a maximum meal of 2 L every 2 h (example from day 0 to 7) with no other restrictions on the total volume of milk replacer per day.

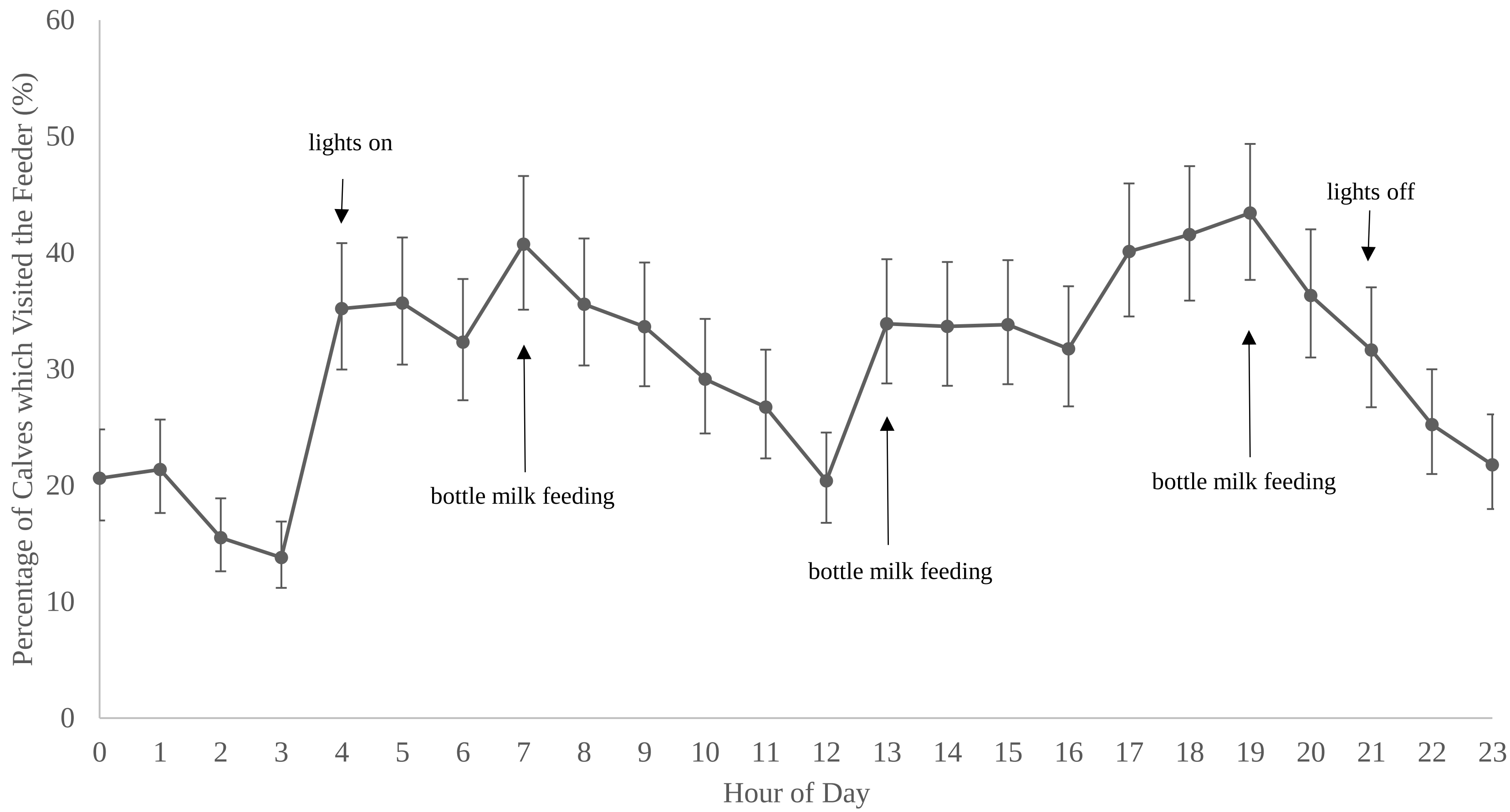

Figure 3.3: The percentage of total calves, which were in the group pen, that actually visited the automatic milk feeder throughout the day. This data is cumulative of 123 calves (81 female, 42 male) over a total of 49 d through a 7 month period. Calves were housed in groups of 3 to 16 calves and feeding from a single AMF. The vertical bars represent 95% confidence intervals, those parallel to each other which do not overlap represent significantly different percentages.

Chapter 4: General Discussion

Important Findings

Calves become primarily in charge of when they feed and can consume smaller meals more frequently when feeding from an AMF. This differs to other feeding methods where producers dictate when the calves are fed and how much milk they may consume. Feeding from an AMF more closely mimics a situation where a calf is left with the dam, having more control over when it drinks and meal size.

A better understanding of how dairy calves learn to use and interact with AMF can contribute to more efficient use of AMF as well as improve calf welfare. There is evidence that only a small percentage of calves learn to use the AMF after a single training session, which leads to a decline in milk intake immediately after introduction to the group pen (Fujiwara *et al.*, 2014). This could result in producers having to spend more time training calves past the initial introduction, and it could result in calves going for longer periods without milk after training, leaving calves hungry. Previous to my work, little was known about the factors influencing how calves learn to use an AMF or how they use the feeder.

In Chapter 2 we sought to understand how a single aspect of stall design influences how quickly calves voluntarily enter and feed from the AMF. We tested 2 different types of stall wall, solid and gated, and hypothesized that calves would learn, and adapt faster, to utilize a gated stall design compared to a solid design. This hypothesis was not supported. Calves were categorized by their willingness to enter the feeder and drink. Those that were moderately difficult to train learned to use the AMF faster on the solid versus the gated design. Calves that were average to train first licked/bit at the nipple 2 times sooner, voluntarily drank 2 times sooner and consumed 3.18 L more milk (over a 72 h period) on average when trained on the solid stall versus gated stall design. The reason for these results is unknown. It is possible that calves were intrigued by the novel plastic material of the solid stalls, or that the solid walls provided a sense of security or prevented calves from getting distracted while in the feeder. The measure of difficulty of training in this study was based on factors like willingness to enter the feeder and how many times a calf broke off the nipple during training.

Group size did not have consistent impact on calves learning to use the AMF. The only outcome which group size affected was the total amount of time calves spent in the feeder, with smaller groups spending more time in the feeder stall than larger groups. It is possible that this is due to a higher number of displacements in larger groups, but was not measured in this study. Sex did not have a large impact either, with the only outcome affected being that female calves required to be retrained on the feeder a greater number of times than male calves.

Chapter 2 is one of few studies to look at physical features of the AMF and how they affect calves learning to use the AMF. A strength of this study was that because the same brand of AMF was used in all cases, only the stall side design was changed, therefore there are no other attributes of the AMF that could be attributed to the observed effects. Because calves were video-recorded, all information from the feeder data could be confirmed, therefore ensuring that all dates and times were correct.

Once calves have learned to use an AMF feeder and no longer require human assistance, there is limited information on how calves utilize the AMF. There are studies where calf milk feeding patterns have been investigated, but these were in relation to either milk feeding level, housing environment, or non-nutritive sucking (Jung & Lidfors, 2001; Appleby *et al.*, 2001; Miller-Cushon *et al.*, 2013; Miller-Cushon *et al.*, 2016). In none of these studies was the focus solely diurnal feeding patterns, and in none of them were calves fed from an AMF, nor were calves ever in groups larger than 3 animals.

In Chapter 3, we analyzed the feeding behaviour of calves in groups using the AMF, to characterize diurnal feeding patterns. Based on previous research of dairy calves and cows feeding patterns (Jung & Lidfors, 2001; Appleby *et al.*, 2001; DeVries *et al.*, 2003; DeVries *et al.*, 2005; Miller-Cushon *et al.*, 2013; Miller-Cushon *et al.*, 2016), we hypothesized that calves would have a diurnal feeding pattern when feeding freely from an AMF. By observing the number of calves that visited the feeder per hour, as well as the total amount of time the feeder was occupied, we determined that calves did have a distinct diurnal feeding pattern. Peak hours of feeding activity were centered around times when humans typically entered the room to bottle feed the younger, individually-housed calves. Feeding activity dropped off once the lights in the room went out at night, and then increased in the morning when the lights came on. This study was observational and, therefore, we cannot assume a causal relationship of these factors feeding patterns observed. However, this is the first study to show that calves living in a group pen and drinking from an AMF do exhibit a non-uniform feeding pattern through the day. Some studies have shown that sick calves could be detected earlier by detecting changes in calf feeding behaviour on an AMF or feeder data (Svensson and Jensen, 2007; Borderas *et al.*, 2009; Knauer *et al.*, 2017). This study could be the start of a new genre of research which helps to establish what a normal calf feeding pattern looks like, and help to improve detection of abnormal behaviour.

Limitations and Future Research

Automatic milk feeders are still a relatively new technology and there is still a lot to learn regarding their use. A better understanding of factors which influence how calves learn to use

AMF as well as how calves use the feeder after they are trained, can help us to prevent and troubleshoot problems in the future. If we can narrow down specific factors that deter calves from voluntarily entering the feeder initially, we can make changes so that calves can adapt faster to using the feeder after initial training. This would hopefully mean less time spent training calves for producers, and calves would be able to feed independently sooner after initial training. By understanding the feeding patterns that develop and why they develop as they do, we could perhaps manipulate those factors that are triggering these peak feeding times to encourage calves to feed at different times, or more often. It could also make early disease detection much easier and, therefore, make for more effective treatments.

This research suggests that stall design does have some impact on how quickly calves can adapt to using an AMF, but it also showed us the importance of how easily calves were to train on the feeder the first time. We trained calves in this study (Chapter 2) based on their age, and given a difficulty of training score based on factors like willingness to enter the feeder and how many times a calf broke off the nipple during training. Due to the resulting influence of difficulty of the outcomes tested in regards to learning to use the AMF, perhaps it would be beneficial to have written criteria in a future study, categorizing these calves more thoroughly, by measuring factors such as: the amount of time it took calves to walk to the feeder or consume their first meal, drinking speed or vocalizations around feeding time during bottle fed meals prior to AMF introduction. These might give some indication of general calf vigor, which could perhaps indicate how well calves will learn to use an AMF and identify calves that are less likely to learn efficiently on the feeder, and would benefit from being trained at a later age. In Chapter 2 we only looked at stall wall design as a factor which might influence calves learning to use the feeder, but there are many other physical factors on commercial dairy farms which might also have impact. Flooring type, and whether calves have to step up to get into the feeder, the type of nipple used, ventilation, and location in the pen could all influence how calves learn to use the feeder.

Knowing that calves feed from the AMF in a certain pattern raises the question of why the pattern is so. It seems that calves do not feed as much during dark hours, their feeding peaks when lights come on, and that there are peak hours around the same time that individually-housed calves (in the same room) are being bottle fed. Research to investigate how these feeding patterns develop in response to these factors would be of great interest. Perhaps even after introduction to the AMF, calves are still associating humans with milk arrival and use it as a cue to enter the feeder. If this is the case, perhaps having someone walk into the room multiple times per day, especially after training new calves, would increase how frequently calves visit the feeder and may help new calves to learn. There may be more competition for the feeder at peak hours and finding a way to evenly distribute feeding times in a large group could decrease competition for the feeder at those hours.

Though there were an upwards of 40,000 data points for Chapter 3, a total of 123 animals could potentially be regarded as a limitation due to the fact that power calculations were not performed prior to data collection. Because data was collected retrospectively, animals were not balanced for age or sex, which could potentially bias the results looking at the effect of these factors. The way that data was collected for this study, using only one week per month, could also mean that the same calf was not represented for a sufficient number of data points. It is hard to determine the impact that this could have on the results, but future studies should take this into consideration prior to beginning data collection.

Implications

Easing the transition onto AMF for dairy calves could improve calf welfare by decreasing stress associated with adapting to a new environment, and could improve calf health. Having to spend less time training and re-training calves on the AMF can allow a producer to focus more time and energy to other tasks, such as maintaining a clean environment or performing more regular and thorough health checks.

Overall, this research does not conclude that producers would be better off choosing one stall design over another, it seems that there are likely other factors which contribute to how easily calves transition to AMF. It would likely be beneficial to be more selective on which calves are trained on the AMF and when, not necessarily using something like age as strict criteria. Calves differ and some learn faster than others, a solid stall design might show a slight benefit over a gated design, but training calves based on their vigour and eagerness to learn might promote better success. After calves have been introduced to the AMF, it is important for them to consume sufficient amount of milk on their own so that they can achieve optimal growth. There is no easy way to teach a calf how to feed itself regularly, but perhaps having people walk the calf barn more often might encourage them to feed. Results of these studies are just the beginning of the investigation into how calves are using AMF, it will be interesting to see what results future studies might find.

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