DAIRY COW ADAPTATION TO AND INTERACTION WITH AN AUTOMATIC MILKING SYSTEM

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ABSTRACT

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Automatic Milking Systems (AMS) represent one of the most recent advancements in milking technology, and their effects on all aspects of the dairy industry need to be considered. Our first objective was to evaluate the adaptation rate of a herd of Holstein dairy cows to being milked by an AMS. Stress-related behaviors during the milking process were recorded for 77 cows as they transitioned from milking in a parlor system to an AMS. Instances of defecation, urination and vocalization in the AMS were greater on Day 0 (day of transition) compared to all other days ($P < 0.05$); milk yield increased after Day 0 ($P < 0.001$). Based on these findings, cows appeared to adapt to milking in the AMS within 24 hours. Our second objective was to determine if cow behavior and gate configuration around the AMS affected the availability of the milking system. Eighty-four cows were divided evenly into two groups (42/group) and observed in the AMS entrance and exit areas, as well as in the adjacent holding area. Cows exiting the AMS were more likely to hesitate when another cow was near the exit gate ($P < 0.01$) or in the general holding area ($P < 0.01$). The duration of hesitation for exiting cows increased linearly as the number of cows in the holding area increased ($P < 0.01$). The AMS time budgets may be dependent on differing social dynamics of a herd. The two experimental groups investigated had differing relationships for successful milking events, back-up events, and AMS empty events. Based on these results, it appears important to consider both cow behavior and gate and alley configuration when introducing a herd to an AMS, although the degree to which it affects individual cows may be variable according to the social structure of the herd in focus.

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ABBREVIATIONS

AMS – Automatic Milking System

DIM – Days in Milk

EC – Electrical Conductivity

BCS – Body Condition Score

DMI – Dry Matter Intake

IMP – Intra-mammary Pressure

SCC – Somatic Cell Count

BU – Back-up

SM – Successful Milking

UM – Unsuccessful Milking

RE – Robot Empty

RC – Robot Cleaning

INTRODUCTION

Since their introduction to the dairy industry in 1992, Automatic Milking Systems (AMS) have generated much interest from farmers and researchers alike. They represent the most recent advance in milking technology, and need to be investigated as to their effect on milk variables, milk yield, milking efficiency, cow behavior, and initial adaptation rate as the cows' transition to a new milking procedure. The first chapter will provide a comprehensive review of the currently available scientific literature on AMS, and will acknowledge some of the areas that require further investigation. The second and third chapters will address two of these areas.

There have been multiple comparisons of stress and behavior responses during the milking process in conventional parlor systems and AMS (Hopster et al., 2002; Gygax et al., 2008; Wenzel et al., 2003). However, it is imperative to first understand the length of time cows require to adapt to the AMS milking process before comparisons between different systems can be made. A comparison between milking systems might be less meaningful if adaptation to the AMS had not yet been completed in these comparative studies. Thus, the second chapter describes the adaptation process over a 32-day period during a transition from a conventional parlor system to an AMS.

Gate and alley positioning are important to encourage efficient cow flow through and around the AMS. However, potential inefficiencies regarding the gate and alley design surrounding the AMS have been reported (Stefanowska et al., 1999). The third chapter describes cow behaviors and interactions with the gate and alley configuration surrounding the AMS, and the resulting inefficiency to the system where applicable. Overall, we expect our results to provide new insights into the interaction between cows and the AMS, as well as the effect this interaction has on cow adaptation to a new milking process and the efficiency of the system.

CHAPTER 1

COMPREHENSIVE LITERATURE REVIEW

INTRODUCTION

The U.S. dairy industry has experienced a broad array of changes within the last 100 years. At the turn of the twentieth century, as the population shifted from small rural farms to large cities, the need for mass-produced and distributed milk products arose. Since then, advances in genetics, milking machines, nutrition and farm management have amalgamated to create the dairy industry we know today. These improvements have led to a six-fold increase in average production per cow, considerably greater total annual milk production, and a sharp decline in total cow numbers from 1900 to the present. Annual milk production per cow has tripled since 1953, from 5,300 lbs. to about 17,000 lbs. today; dairy cow numbers peaked in 1944 at about 25 million and have now declined to about 9 million (USDA/NASS, 2008; Capper et al., 2009).

Much of the technological advancement in the 20th century dairy industry has focused on ways to maximize milk production. Automatic milking systems (AMS) represent one of the most recent technological efforts, offering the potential for frequent milking events without the dependency on human labor (de Koning et al., 2002). The first AMS were installed in the Netherlands in 1992, and by 2009, an estimated 8,000 farms worldwide had adopted an AMS (Svennersten-Sjaunja and Pettersson, 2008; de Koning, 2010). The majority of these are located in Northern Europe and Canada, with only about 1% located in the United States (U.S.) (de Koning, 2010). The reason for slow adoption in the U.S. may be partly due to customer uncertainty with adopting the new technology, and the lack of readily available service providers to assist with mechanistic AMS dilemmas. In addition, average herd sizes in the U.S. are drastically larger than in most countries that have easily integrated AMS technology. Smaller AMS farms may derive more economic benefit compared with larger farms (Armstrong and Daugherty, 1997; Rotz et al., 2003), and thus an AMS

may be a less appealing option for large dairy farmers. However, as research on AMS expands relative to areas of customer and consumer concern, continued adoption in the U.S. is plausible. For example, introduction of the first automated milking rotary (AMR) parlor, which was unveiled by deLaval at the EuroTier 2010 in Hanover, Germany in November, 2010, means there is now a robot capable of serving larger herd sizes. Each AMR, with a 24-stall platform, 5 robot arms, and a maximum capacity of 90 cows per hour, is designed to accommodate 300-800 cow herds.

There has been a range of scientific research on varied aspects of AMS technology and its effect on milk quality, herd health, welfare, behavior, and management. There are multiple differences between AMS and conventional parlors; making targeted research on the new systems necessary. The fully automated milking process that milks on an udder quarter basis and the automated teat cleaning and milking cup attachment process have the potential to affect milk variables and udder health. Motivation to voluntarily approach and enter the milking stalls is necessary for the cows, as they are no longer driven to the milking parlor two or three times daily. Additionally, most AMS are single stall units, requiring cows to milk independently from herd-mates. The motivation for independent approach and entrance to the milking stalls may be dependent on understanding cow behavior, and in turn may affect cow welfare. Simultaneously, management tasks change following implementation of an AMS, as stock-people are freed from the daily milking routine and a large influx of automatically collected data becomes available which can be used to manage the herd.

Since the first AMS was installed in 1992, much research has been investigated these areas. However, as second and third generations of AMS become available, some of the older research has become nearly obsolete. As AMS designs continue to evolve, expand and to improve upon older versions, such as the automatic rotary milking parlor, research must continue to be conducted on

these systems to understand the causes of and consequences of differences between milking systems as well as between the different facilities and management systems that surround them. A compilation of research over the past two decades provides a way to reflect on the history of AMS, as well as a method to identify areas needing additional research for the benefit of the dairy industry as a whole, and more specifically, producers potentially interested in acquiring an AMS.

HERD MANAGEMENT

Advantages of AMS Management

Spahr and Maltz (1997) noted that the most enticing aspect of an AMS to a farm manager may be the relief from the twice or thrice daily milking routine; however, they advise that the AMS should be seen as much more than a substitute of equipment for labor. Automated sensors, particularly those that monitor udder health, milk production, reproductive status, feed intake and body weight changes provide detailed information about each cow that was not easily accessible from previous management and milking systems. As a result of this advancement, the health and production of individual animals can be followed in greater detail. For example, the AMS allows the farmer to assess many aspects of cow health, including somatic cell count (SCC) and mastitis at the level of the udder quarter, which is currently beyond the ability of traditional milk machines. A farm manager who takes advantage of these features would be able to detect small changes within the individual cow to more quickly predict illness, especially mastitis; as well as be able to watch for trends in overall herd production, potentially allowing for early indication of dietary or disease issues within the herd (Sorensen et al., 2002).

One of the main advantages of the AMS lies in the ability to adjust milking frequency on an individual cow basis in order to control milking frequency by production level or at specific stages of

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lactation without incurring any additional labor costs (Svennersten-Sjaunja and Pettersson 2008; Hogeveen et al., 2001). A number of researchers have determined that milking three times daily compared to twice daily enhances milk production by 2 to 20% on average (de Koning et al., 2002; Writz et al., 2004; Wade et al., 2004; Rotz et al., 2003). Svennersten-Sjaunja and Pettersson (2008) determined that cows milked more frequently throughout lactation produced greater quantities of milk compared to cows milked twice daily, irrespective of parity. Tucker and colleagues (2009) suggest cows milked twice daily compared to once daily in the week before dry off produced more milk with no behavioral signs of discomfort after dry off. However, a few authors caution that lower milk yields at dry off can be beneficial, considerably reducing the risk of intra-mammary infections during the early dry period and at calving (Dingwell et al., 1999; Rajala-Schultz et al., 2005).

Most AMS deliver a pre-determined amount of palatable feed to cows during a successful milking event. Feeding concentrates in the AMS has multiple benefits. It provides an opportunity for the farmer to supplement an individual cow to support her stage of lactation, anticipated milk yield, or body condition. Additionally, the use of a highly palatable feed could be a strong motivator, creating a positive association for the cows visiting the AMS. Anecdotally, most AMS distributers indicate that concentrates in the AMS provide a strong motivation for visiting the milking unit. However, there is some conflicting research that argues the significance of offering concentrate in the AMS. Bach and colleagues (2007) and Jago and colleagues (2004) found no significance between the amount of concentrate offered and the need to fetch cows to the AMS. Conversely, Prescott and colleagues (1998) noted an increase in motivation for cows to visit the milking unit when concentrates were present. Furthermore, the authors concluded that the cow's motivation to be milked is weak compared to the motivation to eat, based on results from a choice test between milking and

feeding. These results suggest that relying on the motivation to milk alone may not be sufficient, and offering palatable feed in the AMS is necessary to encourage cows to enter the milking unit.

Disadvantages of AMS Management

While the improvement in milking technology via the use of multiple sensors and data analysis programs in AMS can be beneficial to the manager and cow alike, certain disadvantages are also present. The new dependency on sensors to detect estrus, abnormal milk, mastitis, and other health parameters takes detection out of the hands of the capable farm manager and shifts it to a machine (Spahr and Maltz, 1997). With the automation of these measurements also comes an influx of an enormous amount of data, which could be misinterpreted, used inappropriately, or ignored. As the focus shifts from traditional management methods and skills to a system reliant on new technology the opportunity for, and impact of, computer and machine malfunctions increase. Traditional farm tasks and skills likely will change, and some may eventually be lost.

The computerized management system of the AMS can control the maximum milking frequency for a cow and the maximum amount of feed to be dispensed to her at each milking. However, if the cow does not participate voluntarily in the milking and feeding routine, labor is required to fetch the cow in order to complete the process. Therefore, the cow's ability and motivation to individually access the milking stall become important to the overall success of the system (Hogeveen et al., 2001). Multiple strategies for ensuring or increasing voluntary milking visits will be explored in future sections of this document.

Each single stall AMS is estimated to cost 150,000 to 200,000 U.S. dollars (USD) and can serve approximately sixty cows, although this is dependent on the number of milking events per day the farmer strives to attain for each cow. In comparison, a new conventional parlor is estimated to

cost between 4,000 and 15,000 USD per milking stall, depending upon the type of parlor and whether or not an existing shell (concrete, plumbing, etc.) can be re-used. This means that a double-six parlor might cost between 48,000 and 180,000 USD. Thus, traditional parlors are not always inexpensive ventures. However, the conventional parlor price is singular, while most farms would need to purchase multiple AMS to accommodate the size of their herd. Furthermore, it may be more challenging for a farmer to gradually increase the size of their herd with an AMS than with a conventional milking machine, as the AMS has fairly strict constraints on the number of cows it can service.

An AMS provides the cow with the potential to set her own milking schedule, assuming that the cow is able to act as an individual apart from its herd. It has been demonstrated, however, that low-ranking animals are forced by social competition to visit the AMS at times that are not preferred by more dominant animals, particularly during the midnight hours (Hopster et al., 2002). This suggests that an individual lower-ranked cow may need to be dependent on other cow's schedules to discern suitable milking times, potentially resulting in irregular milking intervals which have been shown to impair milk production (Ouweltjes, 1998; Hogeveen et al., 2001). Therefore, the anticipated increase in milk production with an AMS may not be as fully realized as expected, particularly for low-status cows in the herd.

A number of individual cows may have behavioral or conformational aspects that make them unsuitable for integration into a robotic milking herd. Undesirable teat position and udder quarter size variation create difficulties for cluster attachment in the AMS. In a survey of 15 North American dairy producers, all reported difficulties with teat variation and cluster attachment, resulting in 0 - 3 extra culls per year from an average herd size of 94 cows (Rodenburg, 2002). Miller and colleagues (1995) state that the greatest obstacle for cluster attachment is the distance between rear teats, where

touching rear teats are seen as one by the sensor. Additionally, Rodenburg (2002) found a connection between very high rear udder floors and cluster attachment failure, suggesting that a high rear udder makes it difficult for the sensor to see the rear teats in a horizontal plane. Miller and colleagues (1995) found the AMS has a success rate of 86 - 88% for cluster attachment in a commercial herd, which agrees with Waller and colleagues (2003), who reported a similar success rate of 85%. In the New Zealand 'Greenfield' herd, 8% of potential new cows were rejected from the herd due to conformation that would result in anticipated cleaning and milking difficulties (Woolford et al., 2004). It may prove to be incumbent upon managers to assess udder and teat conformation prior to admitting a cow to the milking herd or to consider genetic selecting for desirable teat placement, to avoid having to devote labor to milking the 15% of the herd that experiences cluster attachment difficulties and failed milkings.

Furthermore, the dairy manager would need to be willing to commit extra time to training his/her herd as a whole to use an AMS, as well as individual animals as they enter the system for the first time. Transitioning a herd from a conventional parlor to an AMS takes approximately three to four weeks of intense labor to achieve a success rate of 80 to 90% cows using the system voluntarily (Rodenburg, 2002).

Management Changes

AMS relieve the dairy farmer from the physical labor of milking, and also provide a large amount of information available for herd management. However, an adaptation of traditional management methods is necessary to acquire independence from the milking routine. Some dairy producers prospectively interested in adopting an AMS indicate that the most attractive features are the potential savings in labor costs and possible increased production per cow (Bijl et al., 2007). A survey including 107 farmers who had already invested in an AMS, found on average an 18% savings

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in labor, equating to 17 hours of labor saved per week (Mathijs, 2004). However, a conflicting study suggests that labor needs with AMS do not decrease as a result of cows that must be fetched in order to attain at least two milkings per day (Bach et al., 2007). Therefore, a number of factors should be addressed when incorporating an AMS in order to successfully decrease labor costs.

To manage herds being milked with an AMS, a modified version of the traditional management cycle is needed. Identified originally as planning, implementation, and control (Dijkhuizen et al., 1992); Devir and colleagues (1993) suggest a modification for farms with robotic milking systems, involving strategic and tactical planning related to management. According to the authors, strategic planning should include defining of objectives, financing, risk analysis, farm organization and production alternatives. Tactical planning includes nutrition, reproduction, milk production, health care, cow replacement, labor and cash flow. The authors further suggest that implementation and control will be modified as well, particularly with the growing amount of data collected on various herd aspects. Cows' behavioral routines are modified substantially with this system, and reinforce the need for reorganization of traditional management and animal care activities. The alteration in management required for successful implementation of robotic milking offer potential advantages to both the herd manager and the cow; simultaneously creating new challenges for both as traditional roles change.

Cow Traffic

A barn being adapted to accommodate an AMS will require alterations to encourage efficient cow traffic and promote normal lying and feeding behavior (Armstrong and Daugherty, 1997). A large waiting area located in front of the AMS has been deemed particularly important by a number of authors (Luther et al., 2002; Melin et al., 2006; Uetake et al., 1997; Hermans et al., 2003) as it

reduces social competition for the AMS, particularly for low-ranking cows. Some researchers have also indicated the need for selection gates throughout the barn to facilitate efficient use of the AMS (Ketelaar-de Lauwere et al., 1998; Hermans et al., 2003; Bach et al., 2009; Stefanowska et al., 1999).

It has been suggested that the number of daily milkings and feedings cows can obtain in AMS are influenced by the design of cow traffic systems within the barn (Ketelaar-deLauwere et al., 1998). 'Cow traffic' refers to the series of gates (or lack thereof) that force the cows to follow a set pattern through the barn. There has been much debate regarding which cow traffic system facilitates high AMS visit frequency and provides adequate access to lying stalls and feed (Ketelaar-de Lauwere et al., 1998; Hermans et al., 2003; Bach et al., 2009; Stefanowska et al., 1999). 'Forced' cow traffic, or 'one-way' traffic forces the cows to be milked prior to visiting the feed alley. Essentially in these systems, a circuit is formed in which cows can move in only one direction to feed, lay down, and be milked. 'Guided' cow traffic uses selection gates to encourage cows that want to access the feed area to walk through the milking unit first. If their designated milking interval has expired, then they must be milked prior to accessing the feeding area. 'Free' cow traffic allows cows to freely access feed alleys, lying stalls, and the AMS at a time of their choosing.

A few researchers have indicated that forced cow traffic encourages more visits to the AMS (Ketelaar-de Lauwere et al., 1998; Bach et al., 2009; Stefanowska et al., 1999). In one such study, the authors reported a total of 953 visits to the AMS with forced cow traffic compared to 703 visits with free cow traffic, over four days of study (Stefanowska et al., 1999). However, the cows in the forced traffic situation had fewer successful milking visits. Average successful milking frequency was comparable and not different among the two traffic systems in this particular study, which agrees with the findings of Hermans and colleagues (2003).

Guided cow traffic may be and a successful intermediary traffic system, compared to free and forced traffic situations. Harms and colleagues (2002) determined that while milking frequency did not vary between traffic systems, the selectively guided cow traffic resulted in the fewest non-milking visits to the AMS (0.7 per cow/day). Moreover, guided cow traffic resulted in fewer fetches per day compared to the free cow traffic situation.

A high percentage of voluntary milking events are necessary to successfully decrease labor on any farm milking with an AMS. Dairy operators in Canada reported fetching 7-32% of their cows once or twice a day to be milked by the AMS (Rodenburg, 2002). While most farmers indicated that minimal effort was required for fetching, the need to fetch cows remains one of the main concerns owners have about robotic milking systems, and may be the single largest factor preventing producers from realizing anticipated labor savings (Bach et al., 2007). In a more recent Canadian survey, producers reported a decrease in the number of fetched cows (4-25%) (Rodenburg, 2007) compared to the numbers reported 5 years prior (Rodenburg, 2002), although the variation in the number of cows fetched between herds was large. The five best herds fetched 2.5% cows on average, while the 5 worst averaged fetching 41.6% of their cows once or twice daily. This indicates that creating conditions that facilitate a voluntary approach to the AMS is still a dilemma, although individual management styles and facility designs may dictate the degree to which fetching is a problem.

Feeding behavior and feed intake are also important aspects to consider when deciding between traffic systems. With guided and forced cow traffic, cows must pass through selection gates before accessing the feed alley, which has the potential to affect daily feed intake and milk production. A few authors have reported increased concentrate and total dry matter intake (DMI) in facilities using forced or guided cow traffic compared to free cow traffic (Melin et al., 2007; Hermans et al., 2003), while others have found that DMI did not differ between the two traffic situations

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(Ketelaar de Lauwere et al., 1998). The number of reported daily meals between the systems has contradictory results; Bach and colleagues (2009) determined the number of daily meals to be fewer with longer meal durations in forced cow traffic, contrasting with the results of others who reported no differences in the number of meals, or visits to the feed alley (Ketelaar-de Lauwere et al., 1998; Lexer et al., 2004; Melin et al., 2007). These discrepancies between feeding studies can likely be attributed to differences in conditions under which the studies were conducted, such as feed palatability, water access, management, and herd health.

Cows have limited access to stalls in the guided and forced cow traffic systems, thus might be expected to spend less time lying each day. However, some studies have found no difference in lying times among guided, forced, and free cow traffic systems (Hermans et al., 2003; Munksgaard et al., 2002; Lexer et al., 2004) while others have observed total time standing in a forced cow traffic situation to be greater compared to free cow traffic (Ketelaar-de Lauwere and Ipema, 2000).

The success of the milking visit can have an effect on how quickly cows leave the milking stall (Stefanowska et al., 1999). AMS exit duration was shorter after a successful milking visit than after a milking failure visits (i.e., a visit to the AMS that resulted in the cows' immediate dismissal because she was early for milking, or incomplete milking due to difficulties with milking cup attachment), and 50% of cows in this study reported back to the AMS within 30 minutes of an unsuccessful visit (Stefanowska et al., 1999). This is the only published research that describes such an effect, indicating a need for more research in this area, including modeling the effect exit duration and unsuccessful visits have on the availability of the AMS. There is enough evidence to suggest that a delicate balance of motivation to enter the AMS must be achieved; voluntary approach to the AMS is necessary to decrease farm labor, but unproductive visits should be avoided to help promote an efficient system and maximize use of the AMS.

COW WELFARE ASSOCIATED WITH THE AMS

The welfare of dairy cows on any farm is affected by multiple factors. Social interactions with other cows, human-animal interactions, management systems, feeding practices and nutrient supply, barn design, climate, and other environmental conditions can affect cow welfare in both negative and positive ways (Wiktorsson and Sorensen, 2004). Compared to cows in conventional milking parlors, cows in an AMS have more freedom to control their daily activities and rhythms, and have more opportunities to interact with their environment. As a result, there may be different animal welfare implications associated with the AMS.

A number of researchers have compared the welfare of cows during milking in an AMS and a conventional parlor system (Hopster et al., 2002; Gygax et al., 2008; Wenzel et al., 2003). Hopster and colleagues (2002) compared differences in behavioral and physiological stress responses of primiparous cows in an AMS and a tandem milking parlor. The authors reported that cows milked in an AMS had a lower heart rate and lower maximum plasma adrenaline and noradrenaline concentrations, suggesting decreased stress during milking. Conversely, Wenzel and colleagues (2003) determined the heart rate of the cows milked in an AMS rose in the minutes before entering the milking stall compared to cows entering a parallel milking parlor. Feed is offered during milking in the AMS, and it should be taken into consideration that the acceleration in heart rate may be due to anticipation of the feed. While increased heart rate associated with a positive experience has not yet been demonstrated in cattle; studies using rats have indicated similar increases in heart rate associated with both positive and negative stimulus (Seward et al., 1969). Alternatively, most AMS are single stall units; resulting in an isolated milking experience that drastically differs from the social milking experience common to conventional parlor systems. Social isolation in unfamiliar surroundings has been suggested to increase stress responses in dairy cattle (Rushen et al., 1999; 2001).

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Hopster and colleagues (2002) noted no differences between an AMS and a conventional parlor when comparing steps and kicks during the milking event. This disagrees with Wenzel and colleagues (2003) who determined that step-kick behavior occurred more often in the AMS compared to the milking parlor. However, management or health differences in the herd, rather than differences in milking systems, could be the primary cause in these discrepancies. For example, Rousing and colleagues (2004) reported that the frequency of stepping and kicking behavior during milking in conventional parlors varied from 6 to 61% between herds.

Even when comparing between types of AMS, there can be differences in cow response. In a direct comparison between a Lely Astronaut A3 AMS, a DeLaval VMS, and a conventional milking parlor, the investigators reported cows in the DeLaval system to exhibit a highest overall stepping rate during the teat cleaning process and milking process, the greater tendency towards kicking, and a higher heart rate during milking compared to the other two systems (Gygax et al., 2008). However, the authors did note that the attachment success rate of the teat cups was less successful in the DeLaval system compared to the Lely AMS (94.3% vs. 98.4% of the milkings). This could indicate that udder conformation and teat arrangement of cows on the farms with the DeLaval systems may have been less than ideal, management or health differences existed between the herds, or that there were imperfections in the design or mechanics of the DeLaval system. The most important difference between the Lely and DeLaval AMS is the service arm and how it moves to clean teats and attach cups, with the DeLaval service arm moving more frequently. Any of these possibilities could help to explain the cows' increased discomfort with this system. Unfortunately, there are no other studies that perform a direct comparison across AMS types, indicating a need for further investigation in this area. If a difference in cow comfort does exist between the different types or generations of AMS, it could help explain some of the conflicts among studies.

HERD HEALTH

Body Condition Score

Few researchers have investigated the effect of transitioning to an AMS on body condition score (BCS). Hillerton and colleagues (2004) investigated fifteen farms from three different countries (Denmark, Netherlands and UK), making the change from conventional milking to automatic milking. The authors determined that BCS varied more by country than it did as a result of the transition to an AMS. Dearing and colleagues (2004) made a similar conclusion; they found no difference in BCS during and after the transition to automated milking. With only fifteen farms to compare, it is possible that the differences exhibited between countries were actually a reflection of differences between herds. Both authors noted a large amount of variation in BCS between herds and between countries irrespective of the transition; therefore BCS may more accurately reflect herd health and management, rather than the type of milking system.

Lameness

Galindo and Broom (2002) noted that a lame cow is less able to cope successfully with her environment, as pain might seriously affect walking and other movements. When combined with automatic milking, this observation becomes notably more important, as a cow with painful feet and legs might be less willing to approach the AMS voluntarily (Rodenburg, 2002). Therefore, it becomes particularly important to investigate locomotion and lameness associated with the AMS. A few researchers have reported no differences in lameness associated with the transition to an AMS (Hillerton et al., 2004; Vosika et al., 2004). This may suggest that lameness is more closely associated with management and facility design, rather than the type of milking system. However, there is a need for additional research in this area. A future comparison of both facility design and

milking system might be ideal, since facility design generally changes with the integration of an AMS.

Current AMS use four load cells on the floor of the milking stall to detect shifts in the cow's body weight. This feature allows the robotic arm to remain directly under the udder at all times. At present, the four load cells do not report the force of each limb separately. However, AMS software could be designed to allow for separate analysis of the force exerted on each load cell, to automatically detect changes in weight distribution indicative of lameness as cows are being milked (Pastell et al., 2008). This could be a powerful management tool, allowing producers to detect problems in early stages when intervention is most effective and least expensive.

Estrus and Estrous Detection

No effect has been seen on reproductive measures related to milking with an AMS (Dearing et al., 2004; Kruip et al., 2000). However, small variations have been observed in conception rates and services to conception one month after installation, and slight decreases in fertility (although not significant) were seen 12 months after installation (Dearing et al., 2004). For the full consequence of any changes in fertility to be studied, longer trials would be required. With these preliminary results from only a few authors, there is a need for further research in this area. However, as with BCS and lameness, fertility may more accurately reflect herd management, rather than the type of milking system.

Transponders allow for automatic identification of the cow when she enters the milking unit. They can also be equipped with activity and rumination monitors. The activity monitors can measure and record the number of steps the cow takes each day. Increased activity is strongly correlated with low progesterone during estrus (Durkin, 2010); therefore it can be used as a timing tool for artificial

insemination. Durkin (2010) recorded estrous detection specificity using an Afikim/DeLaval activity monitor. The author reported an average of 82% detection rate over six trials with a range of 73-92%. The low detection rates likely resulted from a combination of lame cows that did not show activity during estrus and misinterpretation of the data. This automated feature can allow for less intense visual monitoring of estrus, however, the farmer still needs to be able to access and interpret the data from the AMS.

Udder Health and Hygiene

Early studies suggested that milking by an AMS led to poorer teat and udder health compared to conventional milking systems (Ipema and Bender, 1992; Rasmussen et al., 2001; Van der Vorst and Hogeveen, 2000). Ipema and Bender (1992) associated the decrease in udder health with deterioration in teat orifice condition. More recently, Neijenhuis and colleagues (2004) described an overall improvement in teat end condition after one year of milking with an AMS, which was supported by Zecconi and colleagues (2004) and De Vliegher and colleagues (2003), who saw no changes in teat end condition during the transition to milking in an AMS. Earlier models of the AMS typically had a longer machine-attachment time compared to more recent AMS models, and this may have been one of the causes of decreased udder health reported in early studies. Teat trauma can be amplified by over milking (Hillerton et al., 2001), and quarter milking reduces the likelihood of over-milking that could result from one slow quarter in a conventional system.

The udder health of cows is partly dependent on proper milking hygiene (Bartlett et al., 1992), and contamination of the teat orifice can occur easily through bacteria on teat surfaces or on contact surfaces of milking equipment (Hovinen et al., 2005). Therefore, the cleanliness of the teat and equipment prior to milking is essential. In an AMS, the cleaning no longer depends on the vigilance

and decision-making abilities of the herds-person.   There are presently four different devices for teat cleaning used by the various AMS: 1) simultaneous cleaning of all teats by a horizontal rotating brush, 2) sequential cleaning by brushes or rollers, 3) simultaneous cleaning of all teats in the same teat cups as used for milking, and 4) sequential cleaning of individual teats by a separate cleaning device. Extra care may be needed to clean teats in the AMS since none of the four systems dries teats prior to the start of the milking process; thus eliminating another opportunity to remove bacteria from the teat orifice. In today's milking practices, pre-milking teat preparation is not only used to ensure clean teats prior to milking, but also to help stimulate milk ejection through the release of oxytocin. Tactile stimulation of the mammary gland causes alveolar milk ejection through a neuro-endocrine reflex arc (Bruckmaier and Blum, 1996; Dzidic et al., 2004b). As a result, it is necessary to evaluate all types of automatic cleaning devices offered within the AMS in order to assess their ability to achieve proper teat cleaning, as well as stimulation.

Cleaning Success

There is evidence of an association between udder contamination with manure and the number of mastitis bacteria on teat ends (Bramley et al., 1981; Pankey, 1989). Therefore, as a preventative measure, teat cleaning becomes particularly important. Jago and colleagues (2006) observed 130 teat cleaning periods in the AMS and found that only 67% of the cleanings were technically successful (i.e. all 4 teats were completely brushed).   Similarly, Hvaale and colleagues (2002) observed approximately 10 - 20% of the teat cleanings per cow failed technically. Hovinen and colleagues (2005) compared two different types of automatic cleaning systems; the first included a cleaning cup, which used warm water, variable air pressure and a vacuum process that dried the teats; the second included wet rotating brushes to clean the teats from the apex to base and back. The results suggested

that the brushes had better technical success compared to cleaning cups. However, the authors discovered that one-third of all cows in their trial had an unsatisfactory teat cleaning from the AMS. Upon inspection of the experimental herd, the authors reported one of the most important factors for technical success of the automatic cleaning process was teat and udder variation among the herd (Hovinen et al., 2005; Rodenburg, 2002).

Teat Stimulation

Dzidic and colleagues (2004a) evaluated the effect of teat stimulation by two rolling brushes on oxytocin release, milk ejection and milking characteristics in an AMS. The authors recorded quarter milk flow rates when different numbers of brushing cycles were applied to the teats. At the end of brushing, oxytocin concentrations increased with 2-6 cycles but remained low with no brushing; suggesting that between two to six cycles of teat brushing will stimulate proper milk ejection prior to milking in the AMS. These results agree with Bruckmaier and colleagues (2001), who indicate that teat cleaning is necessary to cause oxytocin release and subsequently induce milk ejection.

Dzidic and colleagues (2004b) measured the effects of cleaning duration and water temperature on milk removal and oxytocin release. They measured four different methods of teat preparation during milking. The authors reported no differences in oxytocin levels while using either warm (30-32˚C) or cold (13-15˚C) water. However, at the start of milking without teat preparation, oxytocin remained at a basal level and did not increase until 30 seconds after milking began, indicating the importance for pre-milking teat stimulation (Dzidic et al., 2004b).

MILK QUALITY

Milk color, conductivity, and SCC can be measured automatically by the AMS to help detect milk quality (though SCC measurement by the AMS is not yet approved for use in the United States). Milk color can change as a result of clinical mastitis, although color does not change with sub-clinical mastitis. Therefore, measuring the changes in color of the milk may be helpful for diagnosing potential clinical mastitis cases, although sub-clinical cases may go unnoticed while utilizing this method. Electrical conductivity (EC) is one of the most common indicators used to diagnose both clinical and sub-clinical mastitis and is based on measuring the increase in Na+ and Cl- in the mastitic milk, resulting from inflammation of the udder (Hamann and Zecconi, 1998). However, according to several studies, milk EC measurement may not be sensitive enough to reliably detect subclinical mastitis (Hamann and Zecconi, 1998; Bruckmaier et al., 2004). For example, Hamann and Zecconi (1998) discovered only a slight change in the EC of milk with SCC levels of SCC from 200,000 and 300,000 cells/ml. For this reason, SCC is one of the most used indirect indicators of sub-clinical mastitis, although an effect of season, parity, and lactation stage is often seen (Hamann, 2002).

Klungel and colleagues (2000) examined changes in milk quality after the introduction of AMS on 28 Dutch dairy farms. Somatic cell count (SCC) remained the same throughout the transition, though the author noted that all farms observed had a previously high SCC prior to introducing robotic milking. It should be noted that these data were collected January of 1996 through March of 1998, and multiple changes have been made in the last decade to improve the milking process with an AMS.

Similar to the previous study, Everitt and colleagues (2002) conducted a survey that reported an increase in SCC in months 3, 6 and 12 following installation of the AMS in Swedish dairies.

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Surveys from Justesen and Rasmussen (2000), and van der Vorst and Hogeveen (2000) also find agreement with the previous studies. Both authors reported increases in SCC after installation of one or more AMS on multiple farms. However, a more recent survey contradicts the previous results. Helgren and Reinemann (2004) investigated potential differences in SCC between conventional and automatic milking farms through the use of surveys of U.S. farms. The authors followed the changes in SCC for three years with no overall differences in SCC between the milking systems. These results agree with Billon and Tournaire (2002), who surveyed 46 French farms during the spring and summer of 2001 that had recently transitioned from a conventional milking system to an AMS. The farmers reported no changes in either bacterial counts or SCC after the transition and for up to ten months following.

None of the prior surveys offer information on the type of teat cleaning system used or any information on facility design associated with the AMS. Introduction of an AMS is often accompanied by other changes in the barn such as changes in cow groups, herd management, and the increased reliance on automatically gathered data. Thus, more thorough research is needed that includes the previously mentioned parameters, focusing on the cause for increased (or similar) SCC in automatic milking systems. If, after the inclusion of additional parameters, the results still appear contradictory, it may indicate that herd management, milk collection protocols, and teat cleanliness play a larger role in milk quality than the milking system itself. A recent study conducted on 144 Dutch dairy farms milking with an AMS for at least one year indicated a direct positive relationship between cow hygiene, successfulness of disinfection of the teats prior to milking, and SCC (Dohmen et al., 2010). One of the potential problems with AMS is their inability to discriminate between a dirty and clean udder. A more thorough udder cleaning may be necessary for some cows prior to milking (Dohmen et al., 2010). With this in mind, it may be necessary for AMS farmers to prioritize

cleanliness on their farm until a technological solution for the lack of discrimination for udder hygiene and precise disinfection of teats during cleaning is implemented.

Milk Leakage

It has been suggested that the constant visual and auditory stimuli from the AMS could stimulate ongoing oxytocin release and milk let down, which may predict an increased risk for milk leakage. Only one published report compares milk leakage in an AMS compared to a conventional milking parlor (Pearsson-Waller et al., 2003). The authors observed milk leakage more often and in a larger proportion of cows being milking in the AMS. These results should be interpreted with caution, as there were a higher percentage of first lactation cows (79%) in one of the conventional parlor treatments. However, consequent studies have indicated that causes of milk leakage are not related to milk production, age or stage of lactation (Klaas et al., 2005; Rovai et al., 2007). Rather, intra-mammary pressure (IMP) has been suggested to have a greater influence on milk leakage (Rovai et al., 2007). Although IMP has yet to be assessed in an AMS, there is the potential for greater variation in milking intervals with the AMS, which may result in higher IMP and translate into additional milk leakage.

Klaas and colleagues (2005) measured teat shape, condition of teat orifice and peak milk flow rate, identifying them as risk factors for milk leakage, on 15 commercial farms milking with conventional milking parlors. Milk leakage was observed and recorded in the holding area prior to entering the milking parlor, and was defined as milk dropping or flowing from the teat. Milk leakage rates ranged from 1.2 to 12.3% among herds. Variation among cows within the herd accounted for 89.2% of the total variation in the data. Cows with high peak milk flow, teat canal protrusion, and inverted teat ends increased the risk of milk leakage. Based on these results and the variation in milk

leakage among herds and individual cows, it would be imperative to do a more extensive study on milk leakage in multiple herds milking with an AMS. In addition, such studies should include measurements taking account of teat end condition and previous milk leakage history to ensure accurate interpretation of the data.

AUTOMATIC MILKING AND GRAZING

As dairy farmers worldwide increasingly accept automatic milking systems, there is widening interest in successfully combining AMS with grazing systems, particularly in Europe and New Zealand. While few researchers have explored this area; preliminary results have identified both benefits and obstacles to incorporating a combination system. The 'Greenfield Project', conducted in New Zealand from 2001 until 2008, has provided some important insight from a long-term automatic milking and grazing system (Woolford et al., 2004). A few other authors have contributed to the research in this area, and most are located in Europe (Sporndly and Wredle, 2005; Wiktorsson and Sporndly, 2002; Wredle et al., 2004). Certainly, the need for more research on the combination of AMS with grazing systems is evident if it is to be more widely considered by farmers around the world.

One of the main differences between conventional and automatic milking systems is the reliance on the cows to go voluntarily, and individually, to the milking unit several times daily to be milked (Sporndly and Wredle, 2005). Sporndly and Wredle (2005) suggest that voluntary milking frequency drops to some extent when cows are turned out to pasture. In their survey involving 25 farms with a combined AMS and grazing system, the authors ascertained that 0.2 fewer milkings per cow per day occurred during the farms' pasture months compared to their indoor months (determined seasonally). Therefore, it is important to consider a well-functioning cow traffic system and

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appropriate motivation to induce cows to return to the AMS in order to maintain a comparable milk yield while cows are on pasture. However, a slight decrease in milking frequency may be natural, as energy intake decreases with the pasture-based diet.

As stated previously, well-functioning cow traffic is an important part of successful automatic milking systems. When AMS is combined with a grazing system, the organization of cow traffic becomes essential to the success of the farm (Wiktorsson and Sporndly, 2002). The increased distances between the AMS and feed source (i.e., pastures), and the suggestion that cow behavior becomes more synchronized on pasture compared to behavior in indoor housing systems (Ketelaar-de Lauwere et al., 1999), reflects the need for a methodized cow trafficking system. Without a well-managed traffic situation, the potential for a bottleneck, or absence, of cows at the AMS increases, resulting in a misuse, and therefore less efficient milking system (Wiktorsson and Sporndly, 2002).

Wiktorsson and Sporndly (2002) suggest that one-way gates at the barn entrance, and selection gates at the exit from the barn to the pasture, are the most successful at optimizing cow traffic in an AMS and pasture system. Alternatively, a system where the exit to the pasture can be reached only after passing the milking unit has been suggested to be equally successful as a way to limit the number of animals needing to be fetched to the AMS (Sporndly and Wredle, 2004). In addition to cow trafficking systems, in one instance cows were trained by operant conditioning to return to the barn from pasture following an acoustic signal (Wredle et al., 2004). Innovative motivations, like the one cited above, may help to encourage cows to return to the barn and maintain milking frequency. However, one difficulty with acoustic training is the potential to create a large queue of cows standing in the waiting area if they return to the barn in groups.

Limiting water availability to the barn has been suggested as a way to further stimulate cows to voluntarily return from pasture to be milked (Sporndly and Wredle, 2004; 2005). However, there

is a potential for a decrease in milk production with a limited water intake (National Research Council, 2001). Based upon a study conducted by Sporndly and Wredle (2005), which compared a group of cows with unlimited water access and a group with access to water only in the barn, no differences were seen in milk yield, milking frequency or water intake between the two groups. Relatively high levels of moisture in pasture forage may reduce the effectiveness of water as a motivator when pastures are lush.

Another area of concern when combining an AMS and a pasture system is the distance between the pasture area and the barn. Ketelaar-de Lauwere and colleagues (2000), found no differences between animals walking a short distance to the barn (about 150 meters) compared to a longer distance (about 350 meters) in regards to milking frequencies and total number of visits to the milking unit. However Sporndly and Wredle (2004) found that cows walking a longer distance (260 meters compared to 50 meters) had both a lower milk yield and milking frequency.

It is worthwhile to mention the importance of understanding animal behavior and production as it pertains to a pasture and automatic milking systems. The grazing season is characterized by constant changes in weather, pasture supply, pasture quality, daylight and length, and compared with systems where cows are housed indoors and fed TMR; cows at pasture with an AMS have more freedom to respond to varying environmental conditions (Wiktorsson and Sporndly, 2002). Therefore, it becomes more important to understand how dairy cow behavior can be influenced by different factors. Research from the Greenfield project suggests that cow traffic to the barn begins around sunrise and remains relatively constant throughout the day, with the exception of a lull between the hours of 2 and 6am (Woolford et al., 2004). The authors mention, however, that the activity can be dependent on the time at which a fresh pasture break is available, or on weather conditions, making it important to take these factors in consideration when attempting to maximize

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visits to the barn evenly throughout the day and overnight. Thus, these factors must be considered when determining the number of cows supported by a milking stall, and the ideal number may change throughout the year.

A high level of supplementation in the barn and a more limited pasture area has been suggested to have a positive influence on cow motivation to return to the barn from pasture. Karlsson (2001) suggests cows spend as little as 15% of their day outdoors with little grazing activity when offered a amount of high-quality concentrates indoors. In addition, sward height has been shown to have an effect on milking frequency and cow behavior. In a study by Ketelaar-de Lauwere and colleagues (2000), sward height was measured as it decreased from 11-12 cm to 7-8 cm in a grazing pasture. The authors noted that as sward height decreased, animals spent more time in the barn, and the number of visits to the AMS increased. Greenall and colleagues (2004) suggest that the key to motivating the cows to visit the AMS in a pasture system is flexible farm management and a broad understanding of cow behavior and dietary needs. A manager needs to constantly assess and manipulate the cow's access to the various dietary components available in order to make the farm successful.

FUTURE RESEARCH

Automatic milking systems have been available commercially in Europe since 1992 (Rodenburg, 2002), and had been adopted by more than 8,000 farms by the end of 2009 (de Koning and Rodenburg, 2010). Since then, researchers have been assessing AMS' affect on milk production, labor costs, and welfare of the dairy cow. While a large amount of general research on these subjects has already been completed, greater depth is needed as many questions about the new system still remain.

In a 2007 survey, Canadian dairy farmers indicated the number one reason for investing in an AMS was the potential savings in labor (Rodenburg, 2007). However, some dairy farmers who have implemented an AMS have ascertained that a reduction in labor is not always possible due to a substantial number of cows that need to be fetched to the AMS each day. Rodenburg (2002) suggests that cows needing to be fetched to the AMS may have a problem with mobility, particularly lameness. An automatic milking system offers a unique possibility to measure body weight as it pertains to lameness. By separately measuring the load on each leg when standing in the robotic milking machine, it is highly probable the AMS can identify cases of subclinical lameness, potentially before problems become evident in gait (Pastell et al., 2006). This will not only be beneficial for identifying lame cows automatically, but it also may prove to be a predictor for cows that have an increased likelihood for fetching. However, if lameness is not a direct factor, perhaps fetching is indicative of a lack of motivation for cows to independently approach the milking unit without assistance from human caregivers. Nevertheless, definitive research has not yet been conducted that identifies factors leading to an increased likelihood that a cow will need to be fetched if she is placed in an AMS system.

Many researchers are skeptical that dairy cows are able to act independently from others in the herd (Ketelaar-de Lauwere et al., 1999; Sporndly and Wredle, 2004; 2005), decreasing the efficiency of the automatic milking system by creating a bottleneck at the AMS entry when all cows approach or an idle milking unit at other times. The AMS relies on continuous usage to maintain its productivity and value to the farm. While anecdotally this situation has been contradicted, it is important that it is explored and documented scientifically.

Similarly, facility design has yet to be fully investigated (Rodenburg, 2007). Multiple researchers have examined cow traffic systems and have identified the need for a large holding area

in front of the AMS (Ketelaar-de Lauwere et al., 1998; Hermans et al., 2003; Bach et al., 2009; Rodenburg, 2002). However, a more thorough investigation that includes entrance and exit areas to and from the AMS has been provided by only one author (Stefanowska et al., 1999).

As stated in previous sections of this paper, different management techniques may be confounding factors for the often contradictory studies examining AMS. For example, differences in lameness, estrus detection, body condition, udder health and milk quality may not necessarily be caused by a change in milking systems. Rather, the disparity between results may be more closely associated with differences between farm management and facility design. Future research should be conducted with this in mind. Perhaps a future goal may be to identify flexible management techniques that can be applied to farms with an AMS to help ensure success for both the farm staff and cows during the transition and beyond.

Very little is known about maintenance and the lifespan of automatic milking systems. It is difficult to recommend any new system due to its unknown potential to depreciate in value, perhaps more rapidly than a conventional milking system due to its reliance on technology. While the AMS has been widely adopted in Europe, it has yet to be determined if it is well-suited to US conditions (Rodenburg, 2002). A survey of farmers who have implemented these systems for a number of years may be beneficial to understanding their overall economic worth. A number of different factors will influence the success and value of these systems, including understanding dairy cow motivation and the social dynamics of the herd, as well as reducing the number of cows needing to be fetched to the AMS while subsequently decreasing labor costs. It is important for research to continue in these areas if the AMS is to become a successful milk production unit for farms of all sizes and locations.

CONCLUSION

Over the past few decades, many changes have occurred in the dairy industry. The introduction of automation in milking has generated a great deal of anticipation for the newest milking advancement in the dairy industry. Much of the focus of research on AMS has mirrored consumer interest in milk production, labor, welfare, health, and milk quality; however, more depth and detail is needed, especially as it becomes clear that management continues to play a huge role in the success or failure of the AMS. With so many contradicting results, the need for expanded research is apparent.

CHAPTER 2

DO COWS ADAPT QUICKLY TO BEING MILKED BY AN AUTOMATIC MILKING SYSTEM?

ABSTRACT

Stress-related behaviors of cows were recorded during milking as they adapted to an Automatic Milking System (AMS). Stress during milking can reduce milk yield through an inhibition of oxytocin secretion, therefore it is important to quantify if and how long stress during an adaptation period might last. Four parameters – step-kick behavior both before and after attachment of cups, elimination (urination and defecation instances), and vocalization were measured during milking by trained observers; while milk yield was recorded automatically by the AMS. Seventy-seven cows with acceptable udder and teat conformation that would not interfere with adaptation to the AMS and that were expected to be lactating (18=early (0-100 days in milk (DIM)); 27=mid (100-200 DIM); 32=late (200+ DIM)) for the full duration of the project were divided into two groups (Group 1, n=38; Group 2, n=39) and observed. All cows had been milked previously in a double-six herringbone milking parlor. Data were collected for 24-hour periods beginning on the day the cows transitioned to milking in the AMS (Day 0), and on days 1, 2, 4, 8, 16, and 32 thereafter. Instances of elimination and vocalization ($P < 0.001$) were greater on Day 0 compared with all subsequent days. Milk yield increased after Day 0 ($P < 0.0001$). Primiparous cows (n=28) displayed more step-kick behaviors both before and after teat cup attachment than multiparous cows (n=49) during milking ($P < 0.05$). Greater elimination and vocalization behavior and lower milk yield on Day 0 relative to subsequent days indicated initial stress and discomfort; however, the cows appeared to adapt to the new milking system within 24-hours.

INTRODUCTION

Automatic Milking Systems (AMS) were first introduced commercially in the Netherlands in 1992, and rapidly became popular throughout Europe. Over the course of the last decade, AMS have been adopted by some farms in North America. Currently, about eight-thousand farms worldwide are milking using an AMS with 90% of the world's AMS farms located in north-western Europe (de Koning, 2010). Of the remaining 10% of AMS farms, roughly 90% are located in Ontario and Quebec (Rodenburg, 2007). Perhaps due to the differences in average herd size, the high initial cost of acquiring one or more AMS, or farmer perceptions in regards to technology, the United States (U.S.) has yet to widely adopt the AMS as an alternative to the traditional milking parlor. With this in mind, research aimed at analyzing the ease (or struggle) of the transition between milking with a conventional parlor and milking with an AMS might be beneficial to the industry.

Several studies have compared discomfort and stress behaviors between conventional parlors and AMS (Hopster et al., 2002; Gygax et al., 2008; Wenzel et al., 2003) with some conflicting results. However, the differences between the systems being compared extended beyond the milking process, making it difficult to determine if milking system, management, facility design, or a combination was responsible for observed differences. Most conventional parlors are designed to have multiple cows milking simultaneously and adjacent to each other. The majority of AMS are single-stall milking units, and thus cows are milked in social isolation, separate from their herd-mates. It has been demonstrated that cows milked in social isolation in unfamiliar surroundings show signs of acute stress including decreased milk yield, presumably due to reduced oxytocin secretion (Rushen et al., 2001). In addition, these surroundings have been suggested to increase the incidences of defecation, urination, and vocalization in dairy cows (Rushen et al., 1999). During the transition from a familiar parlor to an unfamiliar AMS milking stall, the novelty of the environment would be

expected to cause such a response independent of changes to the milking process itself. In addition, while milking in a conventional parlor, cows are constantly interacting with human handlers. Conversely, the AMS uses technology to milk cows independent of human assistance. Human interaction (perhaps at least when cows are familiar with this interaction) has been suggested to decrease stress and fear responses (Rushen et al., 2001). Thus, for cows familiar with being milked in the company of other cows and humans, the change to robotic milking might be stressful for several reasons.

Another major change for cows adapting to the AMS is a different motivation to enter the milking stall. Cows are no longer driven to be milked in a large group two or three times daily. Instead, they are expected to voluntarily go to the AMS of their own accord, and as individuals. For this reason, the AMS needs to be viewed as an attractive, rewarding experience, to ensure the cows will return. In most AMS systems, a highly palatable concentrate is offered in the milking stall to entice a visit. However, if the milking process or environmental changes are too stressful for the cow, the addition of a concentrate reward may not be enough to encourage regular visits to the AMS. Cows that do not visit the AMS on their own accord must be physically fetched to the AMS, which increases labor time and cost for the farmer. For this reason, it becomes particularly important to quantify the length of time required for transitioning cows (i.e., making the change from a conventional milking parlor to an AMS) to adapt to milking in the new system. Producers considering acquiring an AMS will then have a more realistic expectation of the initial training period during the transition, and will be provided with information regarding a realistic timeline to achieve a certain percentage of the herd voluntarily milking.

While it is important to measure stress responses during the period between transitioning from a conventional parlor to an AMS, the process of collecting physiological indicators of stress may in

itself act as a stressor (Weiss et al., 2004), confounding the animal's response to the new milking systems. Therefore, in this study we used observational techniques to compare the cow's responses to the AMS over time. Data collection began when cows moved to the new barn to be milked exclusively by the AMS. Vocalization, defecation and urination incidences are considered to be indicators of acute stress or fear in cattle (de Passille et al., 1995; Grandin, 1998); and increased movement (stepping and kicking) is considered a sign of agitation (Grandin, 1993). Therefore, instances of defecation, urination, vocalization, and stepping and kicking during the cleaning and milking process were observed as representatives of a stressful state. Stepping and kicking were recorded both before and after teat cup attachment to the AMS with the expectation that the discomfort associated with the teat cleaning and attachment phase as well as the milking phase would be represented more specifically than if the two phases had been investigated as one. Using this data collection procedure, we expected to create a realistic picture of discomfort and stress associated with the transition to the milking process in the AMS. Our objective was to determine the duration of time it requires cows to adapt to milking in an AMS by measuring behaviors associated with the stress response. It was hypothesized that the cows would initially exhibit higher levels of stress-related behaviors, and these would gradually decrease over time as the cows habituated to the AMS environment and milking process.

MATERIALS AND METHODS

Animals and Husbandry

Eighty-eight lactating Holstein dairy cows made the transition from an old free-stall barn with a double-six herringbone parlor to a new free-stall barn housing two Lely Astronaut A3 Automatic Milking Systems (AMS, Lely, The Netherlands) on July 7, 2009. Prior to the transition, cows were milked three times a day in the parlor and were managed in three groups (two-year olds, multiparous cows, and special needs cows). Once moved to the new facility, cows were divided into two groups balanced for parity and stage of lactation, with each group having access to a single AMS. Seventy-seven cows (Group 1, n=38; Group 2, n=39) were selected for inclusion in the study based on acceptable teat and udder conformation (i.e., it was anticipated that they would have no technical difficulty with teat attachment to the milking cups), and the expectation that they would be lactating for the full duration of the project. Cows were in their first to sixth lactation with an average of 207 ± 15.2 DIM. Except for the 'handedness' of the milking system (i.e., Group 1 had a left-handed milker and Group 2 a right-handed milker; meaning the robotic arm approached the cow from either the left side or right side, respectively), the type of AMS, feeding alley and stall layouts were identical for both groups. Feeding and management practices were also identical for both groups.

For ease of visual identification, cows were marked with individual numbers ranging from 0 to 76 over their rib cages and thurls using either bleaching product (L'Oreal 'Quick Blue', Paris, France) for black areas or black hair dye (L'Oreal 'Starry Night', Paris, France) for white areas. The cows assigned to this experiment had never been milked by an AMS before, however, all had been previously milked in the conventional parlor, and thus had general experience with machine milking. The daily milk yield in the double-six herringbone parlor before the transition averaged 64.15 ± 1.69 pounds for the herd of 88 cows. Free cow traffic was allowed in the new barn (i.e., cows were able to

freely move between the AMS, feeding area, and lying stalls at any time) with the exception of Day 0 (date of transition to new barn) and during limited periods on Day 1 and 2, when cows were driven to the AMS in accordance with a protocol developed by farm staff and Lely representatives to train cows to milk in the AMS (Appendix A). AMS visits were positively reinforced by feeding concentrate pellets in the milking stall at each successful visit.

Summary of Herd Milking Performance During Experiment

Day of Collection	Total Visits	Total Milkings	Total Refused Visits	Average Milkings per Day per Cow	Average Milk Yield
0	191	164	5	2.1	33.1
1	337	262	41	3.2	69.0
2	354	277	55	3.3	72.9
4	308	197	95	2.4	71.5
8	340	223	101	2.7	73.0
16	444	253	187	3.1	76.2
32	386	260	119	3.0	76.4

Table 2.1: Summary of milking performance for all cows in the herd (n=88), including experimental animals (n=77) during the experimental period.

Summary of Daily Weather Activity during Experiment

Day of Collection	Temperature (Celsius)	Humidity (kilopascals)	Windspeed (meters/second)	Precipitation (millimeters)
0	17.9	1.2	3.6	0
1	17.0	1.2	2.1	0
2	20.2	1.4	2.7	0
4	22.8	1.9	3.5	2.8
8	17.8	1.1	2.2	0
16	19.7	1.8	3.0	0
32	20.4	2.2	3.9	46.2

Table 2.2: Summary of daily weather during the experimental period. Weather data were collected from the KBS weather station archives.

Experimental Procedure

Prior to the start of the study, all protocols were submitted to MSU Institutional Animal Care and Use Committee (IACUC), and were deemed exempt from needing IACUC approval as the protocol included observational techniques only. Cows transitioned to the new barn on the morning of July 7, 2009 (Day 0) following a transition protocol devised in consultation with Lely representatives (Appendix A). Cows were milked at 0400 in the conventional parlor prior to being moved into the new barn on Day 0. Cows were manually driven twice to their respective AMS on Day 0 between the hours of 1000 and 0000 (midnight). The first milking of each cow in the AMS involved farm personnel assisting the process by helping guide the robotic arm to the udder, as well as performing manual teat cleaning. By Day 2, free cow traffic was allowed as over 75% of the herd was accessing milker voluntarily. Milking intervals for each cow were programmed in the AMS depending upon stage of lactation and expected milk yield starting on Day 2; cows that were overdue for milking were driven to the AMS every twelve hours. In subsequent sections, cows needing to be driven to the AMS after Day 8 are described as 'fetched' cows.

To measure adaptation rates of the cows being milked by the new AMS, trained data collectors observed the cows once they entered the milking stall of the AMS for each successful milking event. Observations began with each cow's first milking (Day 0) by the new robots, then were conducted on days 1, 2, 4, 8, 16 and 32 thereafter. Data were collected for 24-hour periods on each observation day with observers seated 2.45 meters from each milking unit in identical chairs. Observers recorded the number of steps and kicks both before and after teat attachment to the milking cups, instances of urination, defecation, and vocalizations. Milk yield was recorded automatically by the AMS. The identity of the cow was recorded each time they had to be driven (i.e., fetched) to the AMS after the eighth day of milking in the new system.

Statistical Analysis

Artifacts

During the course of the study, one cow's data were removed from the data set as she managed to switch from Group 2 to Group 1 on Day 3. Since the AMS differ for the two groups in terms of robotic arm orientation, her adaptation rates may have been affected, thus making it necessary to eliminate her data from the records.

Stress-related Behaviors

Data were analyzed with a mixed model procedure (Proc Mixed, SAS 9.1.3, SAS Institute, Cary, NC) to compare the effect of day in the new AMS, parity, and stage of lactation on stress-related behaviors (steps and kicks prior to and after teat attachment, vocalization, urination and defecation instances) and milk yield using the following model:

$$Y_{ijkl} = \mu + G_i + D_j + G_i*D_j + P_k + L_l + P_k*L_l + P_k*D_j + L_l*D_j + e_{ijkl}$$

Where:

$Y_{ijkl} =$ stress-related behavior of interest or milk yield;

$\mu =$ overall mean;

$G_i =$ random effect of group ($i = 2$ groups);

$D_j =$ repeated measures of day ($j = 1$ to 7 days);

$P_k =$ parity ($k = 2$ parity levels);

$L_l =$ stage of lactation ($l = 1$ to 3 levels); and

$e_{ijkl} =$ residual error.

Data for 76 cows were evaluated. Only data from a cow's first milking event on each observation day were analyzed with the intention of controlling for the time of day that the milking events occurred. Results were considered significant at a probability of α less than 0.05. The three-way interaction among parity (primiparous or multiparous), stage of lactation (early, mid or late), and day was evaluated, but removed from the model as it was not significant (p>0.05). Statistical differences were based on differences between least squared (LS) means of day for the following comparisons: steps and kicks before and after teat attachment to milking cups, vocalization, elimination (urination and defecation instances were grouped together), and milk yield. For steps and kicks both before and after teat attachment to the milking cups, data were log transformed to meet assumptions of normality. Data in graphs are presented using LS means estimates. Error bars represent the standard error of the mean (SEM).

Milk yield

For statistical evaluation of milk yield differences before and after the transition to the new milking system, the t-test procedure was used (t-test, SAS 9.1; SAS Inst., Inc., Cary, NC). Data from 48 cows were analyzed. The remaining 28 cows had incomplete data sets (i.e., July 3rd milk yield data were unavailable), and therefore removed from the analysis. The milk yields of cows milked on July 3rd, 2009 (-4 days prior to transition) in the conventional milking parlor and cows milked on July 11th, 2009 (+4 days after transition) in the AMS were compared using a paired t-test. Results were considered significant at a probability of less than 0.05. Error bars represent the SEM.

Fetching

For statistical evaluation of the relationship between day of study and the number of cows fetched to the AMS a correlation analysis was performed (PROC CORR, SAS version 9.1; SAS Inst., Inc., Cary, NC) to calculate Pearson's coefficient of correlation. Data for 88 cows were included. Results were indicated as statistically significant at a probability of α less than 0.05.

Step-Kick Behavior before Teat Cup Attachment

Primiparous cows displayed more stepping and kicking behavior before teat cup attachment compared to multiparous cows ($P < 0.05$; Figure 2.1). A trend was seen in the overall effect of day ($P = 0.09$), with the number of steps and kicks prior to attachment dropping after Day 0.

Steps and Kicks Before Teat Cup Attachment by an AMS

Figure 2.1: Throughout the study, primiparous cows (n=27) displayed more step-kick behaviors before teat cup attachment ($P < 0.05$) than multiparous cows (n=49). There was a tendency for steps and kicks before teat attachment to decrease over time ($P = 0.09$). Data represent least squares means ± SEM for each day.
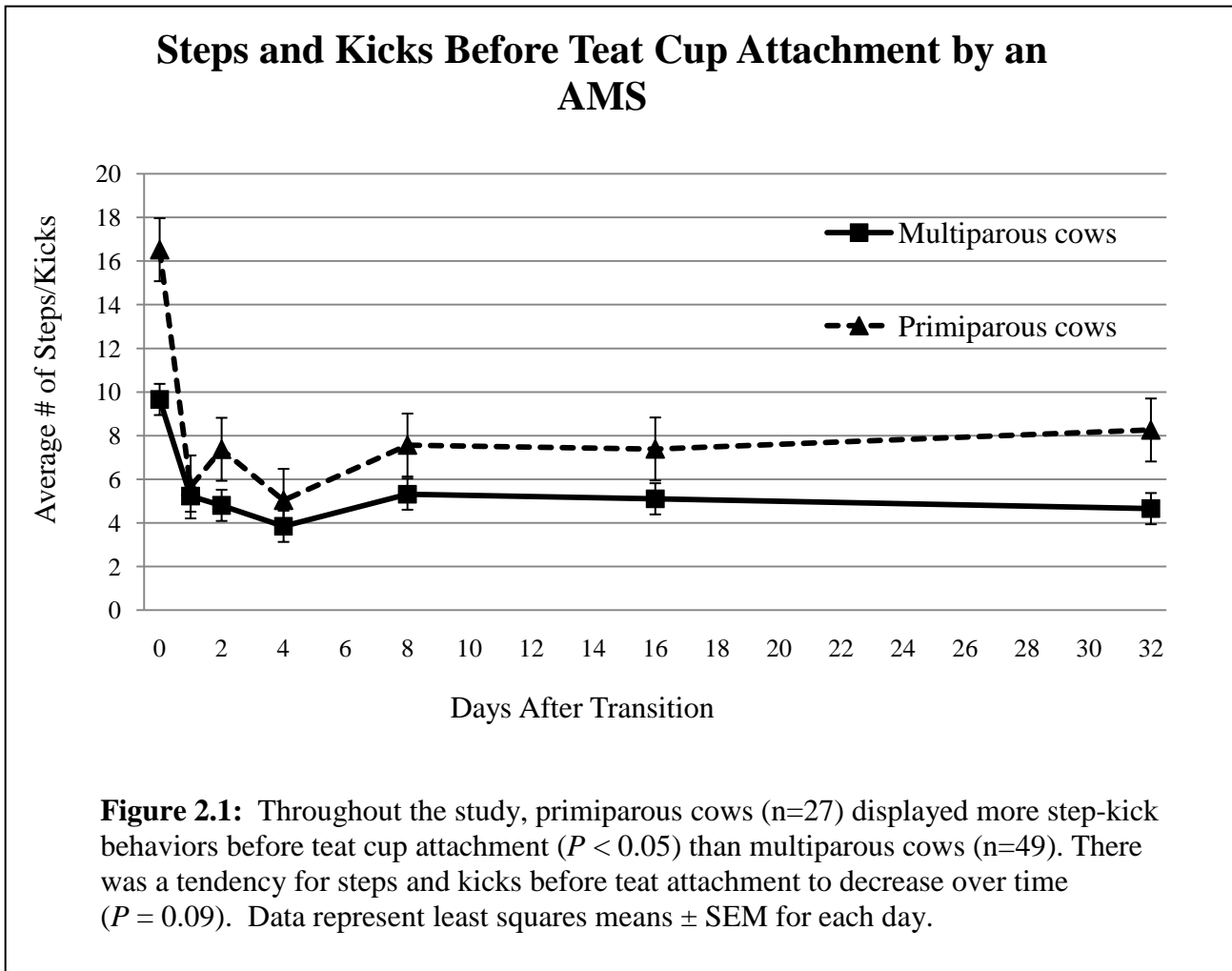
Step-Kick Behavior after Teat Cup Attachment

Primiparous cows displayed more stepping and kicking behaviors after teat cup attachment compared to multiparous cows ($P < 0.05$, Figure 2.2). A trend was seen for the overall effect of day ($P = 0.06$), with the number of steps and kicks after teat cup attachment increasing to Day 4.

Figure 2.2: Throughout the study, primiparous cows (n=27) displayed more step-kick behaviors after teat cup attachment ($P < 0.05$) than multiparous cows (n=49). There was a tendency for steps and kicks after teat attachment to increase over time ($P = 0.06$). Data represent least squares means of untransformed data ± SEM for each day.
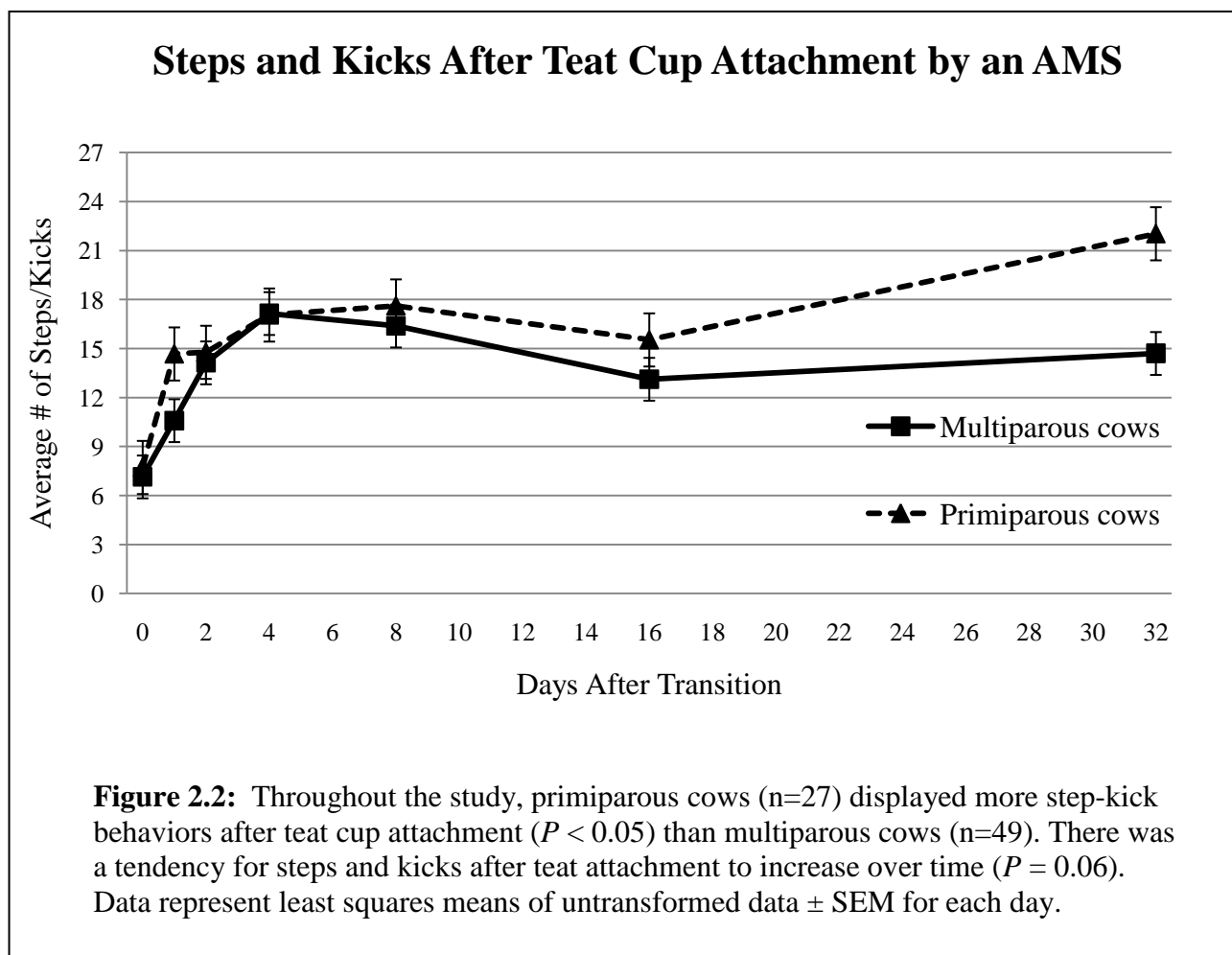
Elimination and Vocalization Instances

       Elimination (i.e., combined instances of urination and defecation) decreased between Day 0 and Day 1 ($P < 0.001$). Similarly, vocalization instances decreased between Day 0 and Day 2 ($P < 0.001$), and remained at 0 for the remainder of the study (Figure 2.3). There were no effects of parity or DIM for either factor.

Figure 2.3: Total instances of both elimination and vocalization behaviors decreased over time ($P < 0.001$). Different lower case letters indicate differences between those data points ($P < 0.05$).
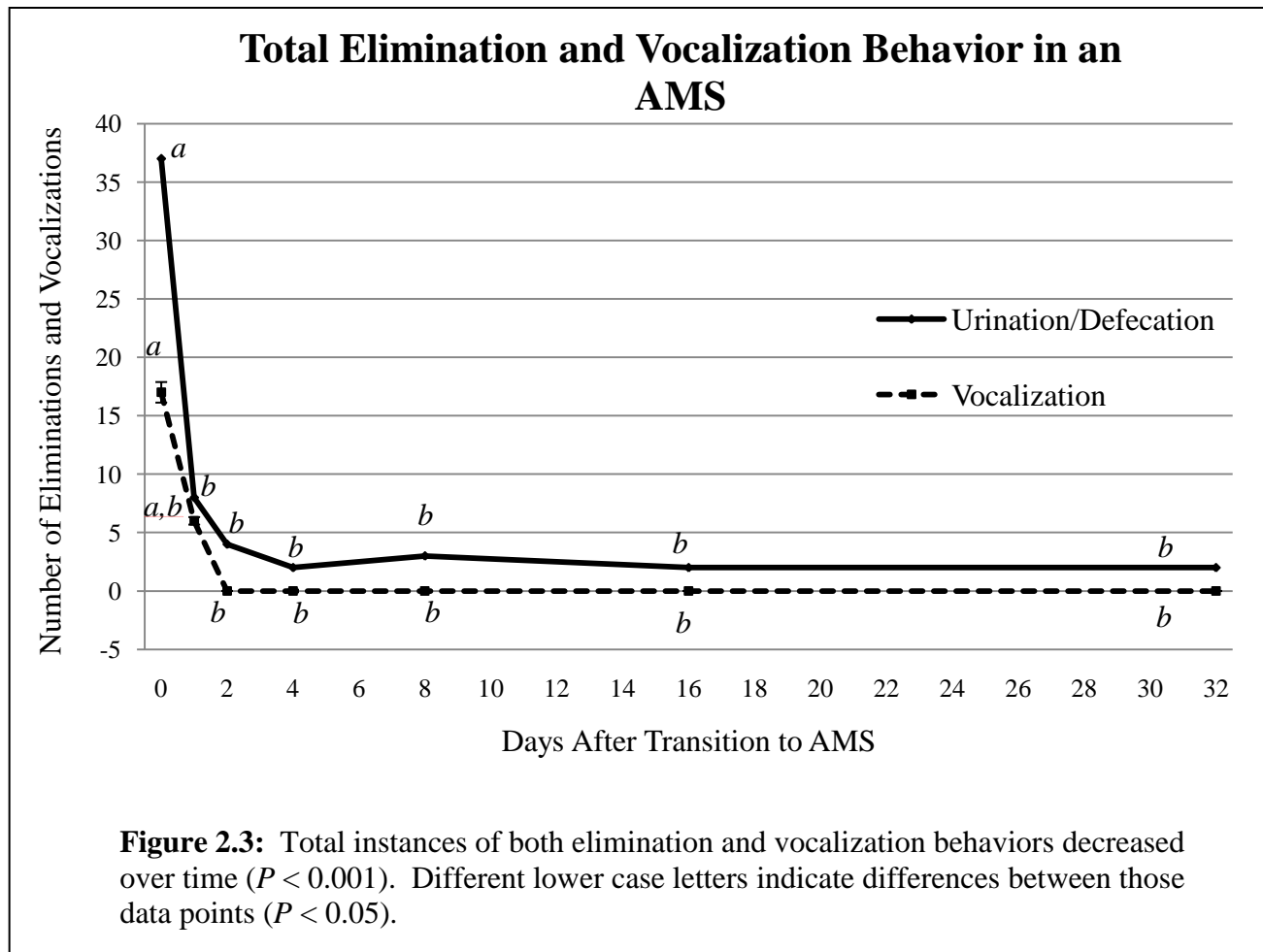
Milk Yield after Transition

Day, parity (multiparous = 73.0 ± 3.2; primiparous = 58.1 ± 3.4), and DIM (early = 74.8 ± 3.5; mid = 66.5 ± 3.5; late = 55.3 ± 3.3) affected milk yield ($P < 0.05$; Figure 2.4). Multiparous cows and those in early lactation had greater milk yields ($P < 0.05$). Milk yield on day 0 was lower than all other days ($P < 0.05$). There were no interactions ($P > 0.05$).

Figure 2.4: The main effect of day was significant ($P < 0.05$). The presence of an asterisk indicates a difference from all other days ($P < 0.05$). Data represent means ± SEM.
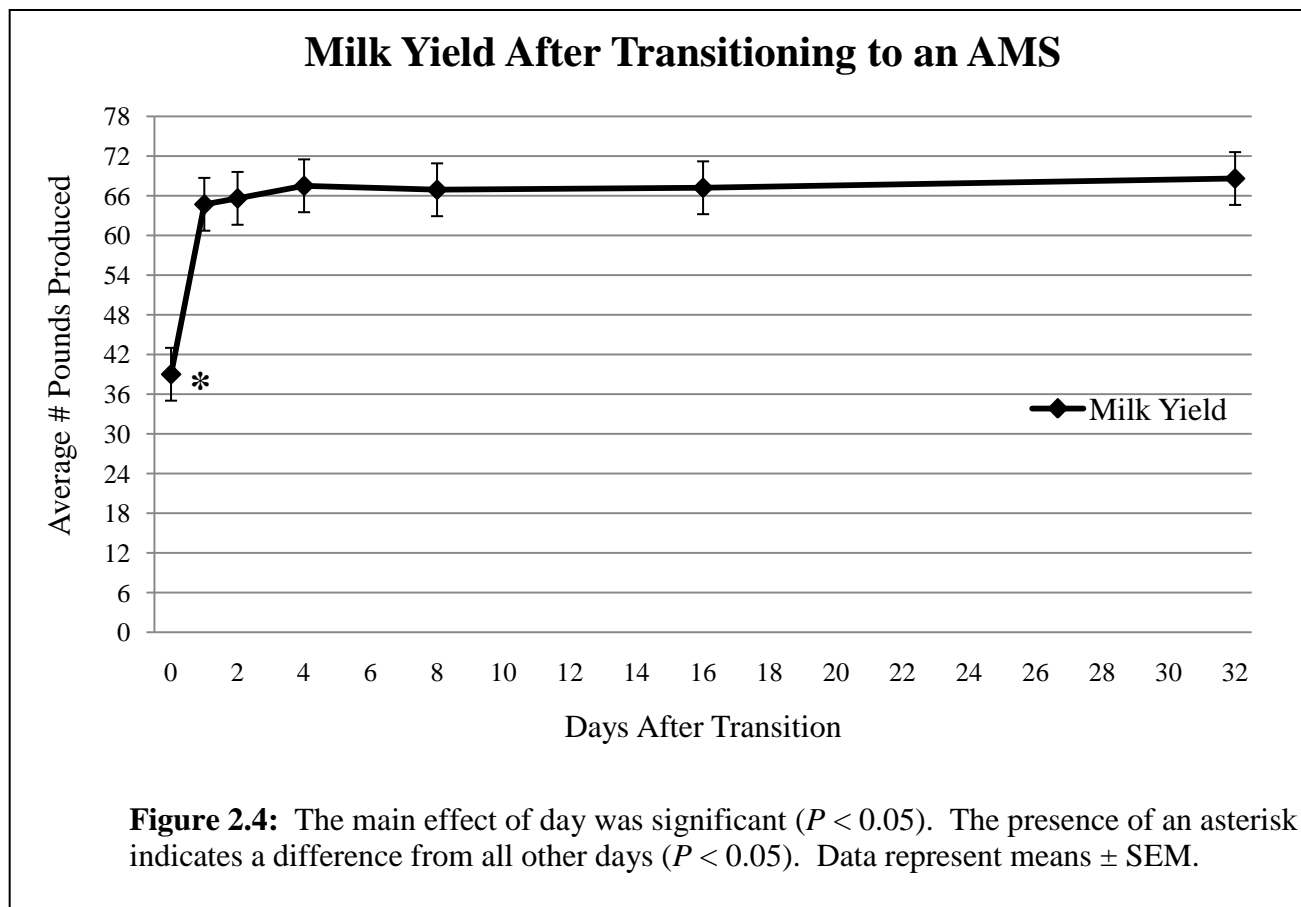
Milk Yield ± 4 Days

Milk yield increased after the transition to the AMS from 64.2 ± 1.69 to 68.3 ± 1.70 ($P <$ 0.001; Figure 2.5).

Figure 2.5: Milk yield four days after the transition to an AMS exceeded the average attained four days prior to transitioning to an AMS ($P < 0.001$). Data represent means ± SEM.
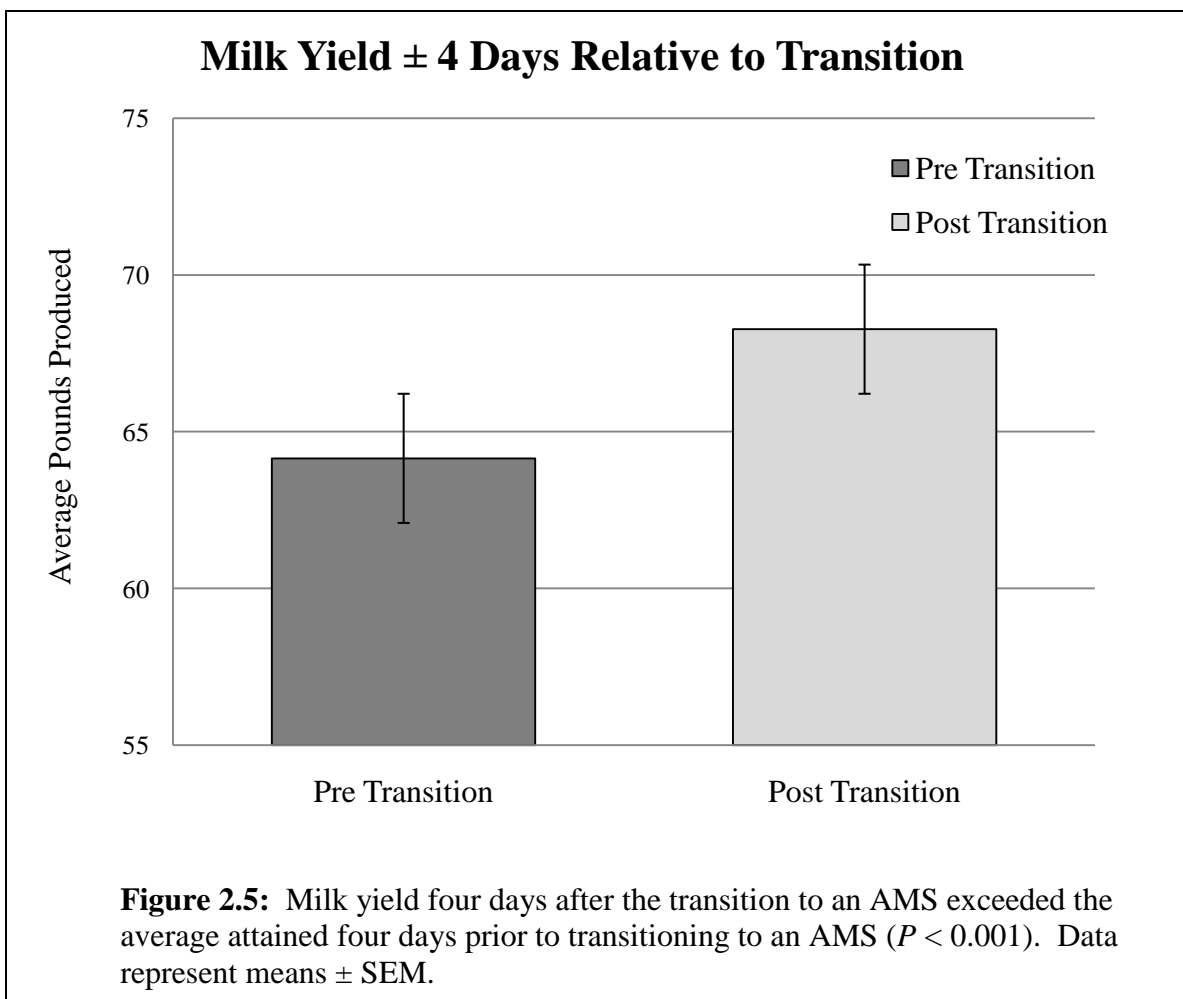
Fetched Cows

Data on the number of cows that had to be fetched to milk were recorded beginning on Day 8 until Day 32. As shown in Figure 2.6, the relationship between the number of cows fetched and the data were linear and negatively correlated. Pearson's coefficient of correlation was r = -0.73 ($P <$ 0.001).
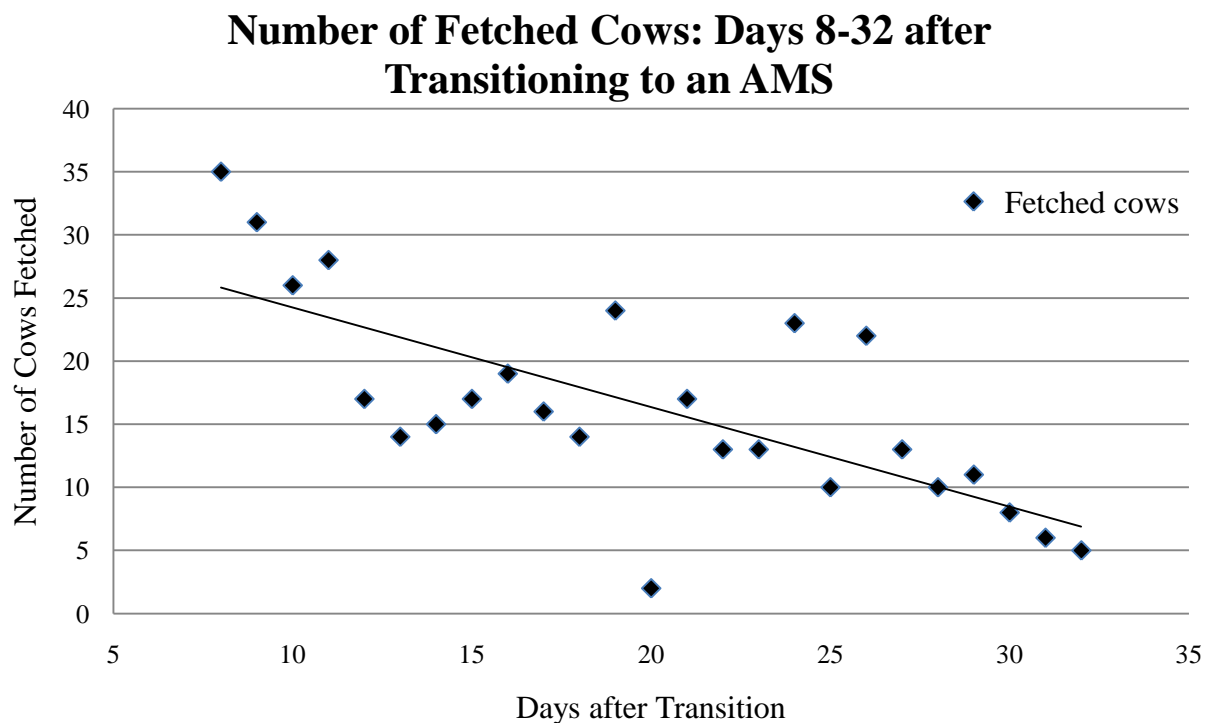
Figure 2.6: Relationship between the date (x) and the number of fetched cows (y): y = -0.67 + 0.13x; r=-0.73 ($P < 0.001$). July 15th = Day 8, August 8th = Day 32.

DISCUSSION

Novel environments have been associated with increased stress levels in cattle (Grandin, 1997). Furthermore, increased stress levels have been associated with a decrease in oxytocin release during milking, subsequently leading to decreased milk yields (Bruckmaier and Blum, 1998) and decreased animal welfare. When cows are moved from a conventional parlor system to an AMS they are exposed to a novel milking environment, and previous research about acclimation rates during the transition to an AMS is limited (Weiss et al., 2004). The current study may provide interested farmers with realistic expectations for their cows during the transition period from conventional parlors to AMS; and perhaps more importantly, ensure cows are not chronically stressed following the transition, as this can lead to poorer health and welfare (Trevisi et al., 2006). However, it should be noted that the transition protocol used for this study (Appendix A) may not be similar to those recommended by other manufacturers of AMS; therefore, these further studies should examine the response to the transition when different protocols are followed.

During the cow's first visit to the AMS (Day 0), they frequently vocalized, eliminated, stepped and kicked prior to teat cup attachment, suggesting discomfort or stress with the novel milking environment. Vocalization, defecation and urination incidences are considered to be indicators of acute stress or fear in cattle (de Passille et al., 1995; Grandin, 1998). Furthermore, increased movement (stepping and kicking) by cattle is considered as a sign of agitation (Grandin, 1993). The high incidences of vocalization, elimination, stepping and kicking on Day 0 suggest discomfort or stress during the initial milking event. The AMS was a completely novel milking unit for the cows, and novelty has been demonstrated to be a potent stressor for cattle (Grandin, 1997). This may be one of the reasons why stress and discomfort behaviors were present to a greater degree during the first day. However, in less than 24 hours, stepping and kicking prior to teat attachment

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dropped and vocalizing and eliminating in the AMS stall nearly disappeared. The rapid decline of these stress-related behaviors could be due to the cows becoming more comfortable with the milking stall, barn environment, and robotic milking equipment and process. It is important to note that the effect of group was not significant, indicating that there were no differences in adaptation rates between the two groups, despite having access to differently oriented AMS (e.g., left vs. right handed milking systems).

Curiously, steps and kicks after teat attachment to the milking cups (i.e., during the milking process) increased between Days 0 and 32. There are a number of possibilities as to why this may have happened, although it is impossible to accurately identify one answer without additional research. During the first month, the new barn's manure scrapers were not working well, leading to a large amount of manure in the barn and consequently a large number of flies. We were unable to discriminate between steps and kicks related to fly avoidance versus steps and kicks linked to discomfort with the milking process, and we could not accurately quantify the number of flies in the barn. However, similar increases in steps and kicks prior to teat cup attachment were not seen on Day 32, suggesting that fly avoidance may not have been the cause.

Another possible reason the cows kicked more while being milked by the robots is the difference in pulsation ratio between the old conventional parlor and the robot. The previous parlor milking system had a pulsation ratio of 60:40, while the AMS milked at a pulsation ratio of 65:35. The small change in pulsation ratio could have been exacerbated by minute changes in any of the four milking phases or in the teat cup liner composition and shape. The difference in the milking and resting ratio could have led to some discomfort during milking as the teats adjusted to the change (Thomas et al., 1991; 1993). However, we would have expected to observe a greater step and kick response during the first few days following the transition to the AMS to support this explanation.

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It is important to note that primiparous cows exhibited greater step and kick responses compared to multiparous cows. It is possible that the step and kick response observed in the primiparous cows was exacerbated by their smaller stature. They had more room to move throughout the milking stall compared to the majority of the multiparous cows, and may have taken advantage of that fact. Jago and colleagues (2011) observed a similar phenomenon in their group of primiparous cows. The large increase in step and kick response at Day 32 may have been a reflection of the cows' anticipation of their upcoming release from the stall at the end of their milking event. It is possible that between Day 16 and 32 the cows learned to predict when their milking event was nearing the end, and began to exhibit increased restlessness in response to their anticipated release. Increased restlessness may have been more obvious in the primiparous cows, due to their smaller stature and greater ability to move around within the milking stall.

Importantly, milk yield, which had dropped from an average of 64 lb per cow prior to the transition to an average of 35 lb per cow in the first 24 hours in the new barn, rebounded to nearly 70 lb per cow per day within four days. These results are similar to those reported by Weiss and colleagues (2004) who reported an initial reduction in milk yield during the first few AMS milking events when transitioning from a conventional parlor. The likely mechanism underlying these results involves a stress-induced inhibition of oxytocin release (Bruckmaier and Blum, 1998). Milking cows in an unfamiliar environment has been demonstrated to reduce oxytocin release, subsequently leading to lower milk yields (Bruckmaier et al., 1993; Rushen et al., 2001). In addition, cows may have decreased their water intake during the morning of the transition, affecting their milk yield throughout that day. The unfamiliar environment coupled with a change in the milking process may be the reason for the severe decrease in milk yield seen on Day 0. However, it is important to note that during the first milking, the robot must learn each cow's udder and teat conformation. This process

can take several additional minutes, which caused the first milking events to be longer than all later milkings. This may have helped contribute to the high number of stress-related behaviors recorded on Day 0. Regardless, by Day 1 milk yield had returned to 65 lb, indicating that the cows had become comfortable with the new milking process and stalls.

Another indication that the cows adapted quickly to the AMS were the number of cows voluntarily milking. Within a week of introducing the cows to the robotic milkers, over 60% of the herd was milking voluntarily. After two weeks, over 75% of the herd was milking voluntarily and after one month 95% of the herd was milking voluntarily. In terms of labor, this meant that only 5 cows needed to be fetched every 12 hours for milking while the remainder of the herd went through the robotic milkers voluntarily over 2.5 times per day. The voluntary milking rates in the current project were slightly lower than those described by Weiss and colleagues (2004), who reported a 97% voluntary rate 2 weeks after transitioning to an AMS. A study by Rodenburg (2007) reported a large variation of voluntary milking between 43 surveyed herds. Five herds at the top of the scale averaged 97.5% of cows voluntarily milking, while the five herds at the bottom averaged 58.4% (Rodenburg, 2007). No obvious reason for such variation was provided, but perhaps in the future, an adaptable protocol and list of recommendations may be available for farmers considering making the switch to robotic milking in order to maximize the number of voluntary milking events exhibited by each transitioning herd.

CONCLUSION

In summary, according to most of the measures examined, the cows had adapted quickly to being milked by the AMS. One puzzling piece was the increase over time in the number of steps and kicks following teat attachment during the milking process. It is important to further investigate the cows' rate of adaptation from a conventional parlor system to an AMS. It should be noted that this experiment examined only one herd of cows with one management protocol and one type of milking system. It will be important for similar experiments to be completed to determine if these results are consistent with findings from other farms. A future goal for the industry might be to develop a protocol for the transition to milking with an AMS that can be customized based on the particular management restrictions, barn, herd size, and overall goals of the farm.

CHAPTER 3

EFFECTS OF EXIT ALLEY BLOCKING AND BACK-UP INCIDENCES ON THE ACCESSIBILITY OF AN AUTOMATIC MILKING SYSTEM

ABSTRACT

Facility design can impact the accessibility of an Automatic Milking System (AMS). In particular, gates and alleys positioned around the AMS may impact cow traffic and cow behavior; potentially affecting the duration of time the AMS is available for milking. Eighty-four Holstein cows of various parities and days in milk (DIM) were divided between two groups, each with access to its own AMS. Cow locations and behaviors in the AMS entrance and exit areas, as well as in the adjacent holding area, were recorded continuously for 14 days. Cows receiving a 'no-milking' decision took longer to exit the milking stall, and were more likely to circle and re-enter the AMS compared to cows receiving a milking decision ($P < 0.01$). Cows exiting the AMS were significantly more likely to hesitate when another cow was near the exit gate ($P < 0.01$), or in the general holding area ($P < 0.01$). Cows in late lactation hesitated for long periods during exiting more often than cows in other stages of lactation ($P < 0.01$) regardless of whether cows were in the holding area. Primiparous cows were more likely to block other cows trying to exit ($P < 0.05$) compared to multiparous cows. Blocking events leading to an AMS 'back-up' had no relationship with successful milking events in group 1 (r = 0.01, $P = 0.69$), but shared a weak negative relationship in group 2 (r = -0.49, $P = 0.07$). The AMS was empty (not occupied) on average for 10% and 18% (group 1 and 2, respectively) of the day; therefore it was possible that the duration of back-up events would be cushioned by the amount of time the AMS was empty. The duration of back-up events and AMS empty events had a negative relationship in group 1 (r = -0.74, $P < 0.01$), but no relationship in group 2 (r = -0.14, $P = 0.61$), suggesting that the relationships may be dependent on group social dynamics.

INTRODUCTION

An Automatic Milking System (AMS) relies on a cow to voluntarily enter and exit the milking stall without assistance from farm personnel and as an individual apart from its herd. As a result, understanding the interaction between cows and their environment that influence movement through the AMS becomes imperative to the success of the system. In order to ensure a high percentage of individual voluntary milking visits, cows must be motivated to enter the milking stall of their own accord. The motivation for cows to be milked is weak in and highly variable between cows relative to the strong, fairly consistent motivation cows have to eat (Prescott et al., 1998). For this reason, a palatable feed concentrate is usually offered in the AMS milking stall. Additionally, a number of researchers have identified the importance of a large holding area near the milking stall to reduce social competition for access to the AMS (Hermans et al., 2003; Melin et al., 2006; Rodenburg, 2007). The holding area, which is an open area in front of the milking stall, is designed to provide an area for cows to queue and wait to access the AMS. A minimum of 6.09 meters of space between the free stall area and the milking stall (i.e., the holding area) is recommended to encourage efficient traffic flow from stalls into the AMS (Rodenburg, 2007).

Most AMS incorporate entrance and exit alleys and gates to encourage an efficient queue prior to and after milking; potentially reducing negative social interactions that might influence AMS visit frequency. A one-way exit alley 1.83 meters or more leading away from the milking stall has been recommended in order to help facilitate exit traffic and decrease aggressive interactions (Rodenburg, 2002). However, little research has investigated the effectiveness of these holding area and entrance and exit design recommendations. Stefanowska and colleagues (1999) reported a decrease in the rate of movement of cows in the exit alley when other cows were present in the

holding area. Additionally in this situation, the exiting cow and the cow(s) in the holding area engaged in aggressive interactions more than fifty percent of the time.

When designing the new barn at the Kellogg Biological Station (KBS) Pasture Dairy Research Education Center (PDREC) at Michigan State University, a 7.32 meter holding area and 2.45 meter long entrance and exit alleys were incorporated to help facilitate cow traffic in and around the AMS following the recommendations described above. Despite the inclusion of these features, cows were frequently observed hesitating in the exit alley. Furthermore, cows in the holding area were regularly observed blocking cows attempting to leave the exit alley by positioning themselves at the end of the alley near the one-way exit gates. Occasionally, these blocking events would lead to a 'back-up' of cows in the exit alley, and recently milked cows were unable to completely exit the milking stall. As direct consequence of this back-up, the AMS was not able to accept a new cow for milking. Thus, despite following recommendations, anecdotal observation suggested several cow-traffic problems which could potentially affect the efficiency of the system and impact individual time budgets of cows. These problems may cause a decrease in the availability of the system which could in turn equate to fewer milking events each day. In addition, negative social interactions at the AMS may reduce the motivation of cows being blocked to revisit the milking stall of their own accord.

The objective of this study was to investigate factors relating to potential inefficiencies of the holding area, gates and exit alley design near the AMS at the KBS dairy farm. Descriptions of factors relating to hesitation in the exit alley, the effect of unsuccessful milking visits (i.e., cow enters the milking stall and rejected due to a recent milking event) on the efficiency of the system, and the characterization of cows that hesitate and cows that block were made to provide insight into the potential problems associated with facility designs. Additionally, the relationship between blocking and successful milking events was investigated to further evaluate the effect facility design and cow

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behavior has on the efficiency of the AMS. We hypothesized that: 1) unsuccessful milking events would lead to decreased AMS exit duration and would result in more frequent circling compared to successful milking events, 2) the duration of hesitation in the exit alley would increase with the presence of cows in the holding area or near one-way exit alley gates, 3) cows that hesitate would share similar characteristics to each other (e.g., would be primiparous, in late lactation with no horns), and cows that frequently block would share similar characteristics (e.g., would be multiparous, in early lactation with horns), and 4) lastly, we hypothesized that back-up events would negatively impact the availability of the AMS by reducing the duration of successful milking events.

MATERIALS AND METHODS

Animals and Husbandry

Eighty-four lactating Holstein dairy cows were used to analyze the efficiency of the Kellogg Biological Station's (KBS) PDREC AMS facility design by assessing cow behavior in and around the AMS. Cows were divided into two groups (n = 42/group), balanced for parity and stage of lactation with each group having access to a single AMS. Cows were chosen to participate in the study based on the expectation that they would be lactating for the full duration of the project. Cows were in their first to seventh lactation with an average of 194 ± 13.9 days in milk (DIM).

AMS entrance and exit gate designs for cow traffic flow were mirror images between the two groups because the 'handedness' of the milking system was different between groups. Group 1 had access to a left-handed milker, and Group 2 had access to a right-handed milker (i.e., the robotic arm approached the cow from either the left side or right side of the cow, respectively). Gates for Group 1, which accessed the right-handed AMS, forced clockwise cow traffic through the AMS, while gates for Group 2, which accessed the left-handed AMS, forced counter-clockwise traffic through the AMS

(Figure 3.1). All gates and alleys were of equal lengths for both groups. The entrance alley (where cows queue to access the milking stall) was 2.01 x 0.91 meters. The exit alley (which led away from milking stall) was 2.08 x 0.91 meters (Figure 3.2).

Gate and Alley Configuration for Group 1 and Group 2

Feed Alley

Computer Feeder

Holding Pen

Waterer

Group 2 Alley

Entrance

AMS Group 2

Free Stall

Center of Barn

AMS Group 1

Group 1 Alley

Waterer

Exit

Computer Feeder

Holding Pen

Feed Alley

Figure 3.1: Cow traffic moves in a counter-clockwise direction through the AMS in Group 2. Traffic moves in a clockwise direction in Group 1.
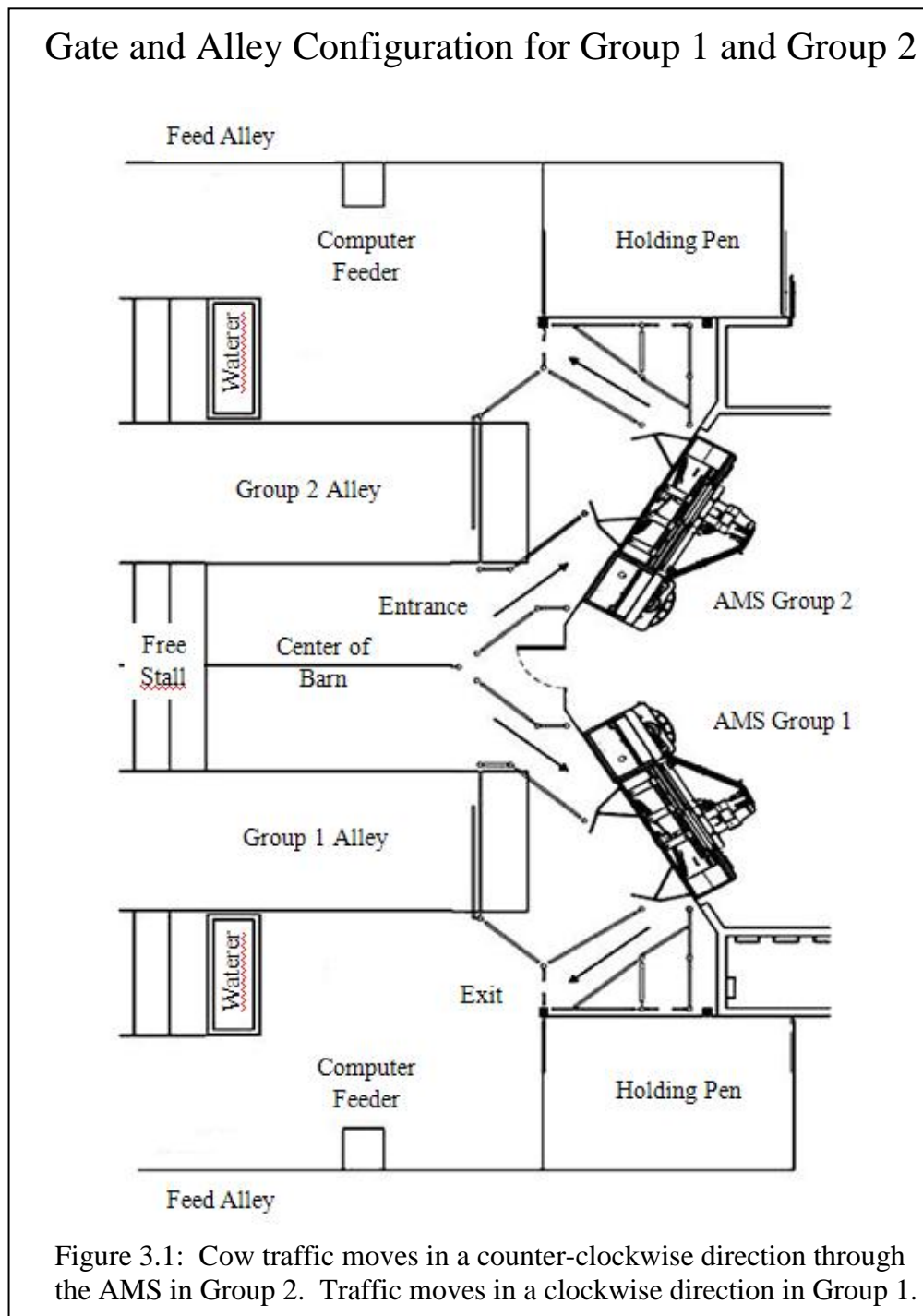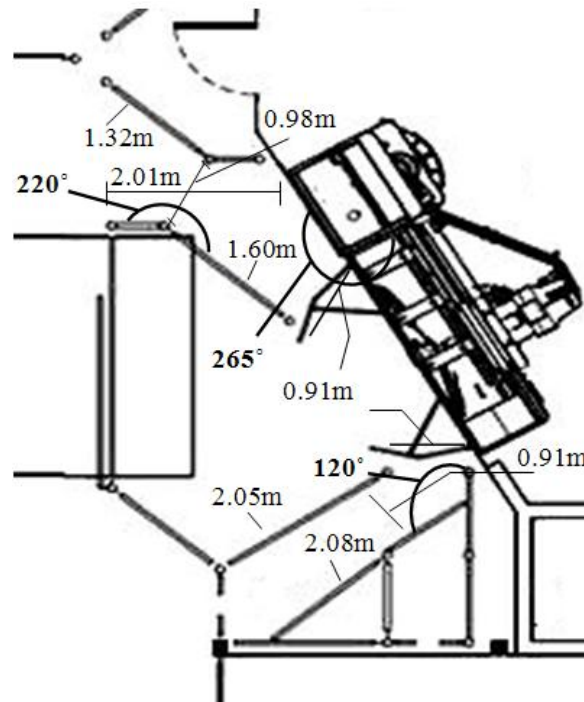
Figure 3.2: Dimensions for entrance and exit alleys are identical for both groups (Group 1 depicted above).

The type of AMS (Lely Astronaut A3, Lely Industries N.V., Maassluis, the Netherlands), feeding alley, stall layouts and management practices were identical for both groups. Feeding of a Total Mixed Ration (TMR) occurred twice daily (0500 and 1500) and both rationing and scheduling were identical for the groups. Cows were offered concentrate pellets during the milking process; amount of concentrate was dependent upon the individual cow's projected milk yield (Table 3.1). Foot baths were present in the exit alleys, and filled on alternating days with copper sulfate or water. An electrical movement inductor was present in both AMS and used to encourage cows to step out of the milking stall after 20 seconds of hesitation. The shock impulse duration was 10 seconds, and occurred a maximum of 3 times (after 20, 40, and 60 seconds of hesitation). The shock intensity

increased with each impulse; the intensity began at 2 kV (kilovolt), 22 mJ (megajoule) and ended at 8.5 kV, 60 mJ.

Table 3.1: Ingredient composition of concentrate pellets fed in AMS (% of DM)

AMS Concentrate Pellet Details	
Ingredients:	Percent Dry Matter:
Soy Hulls	60.6%
Corn fine grind	13.3%
Corn Gluten Meal	4.6%
Soybean Meal	3.6%
SurePro – LOL[1]	3.6%
Molassess Cane	2.2%
Tallow	1.5%

[1]SurePro LOL (Land O Lakes) mix contained 46.5% crude protein (CP), 0.8% fat, 4.5% acid detergent fiber, 6.5% neutral detergent fiber, 0.25% calcium, 0.67% phosphorus, 74% of CP undegraded intake protein, 26% of CP degraded intake protein, 18% of CP soluble intake protein, 28% non-fiber carbohydrate, 1.95% potassium, and 0.3% magnesium.

Experimental Procedure

Prior to the start of the study, all protocols were submitted to MSU Institutional Animal Care and Use Committee (IACUC), and were deemed exempt from needing IACUC approval as the protocol included observational techniques only. Six Sony Super HD cameras (Sony Corporation, Tokyo, Japan) and a 16-channel G-Max 9000 series Digital Video Recorder (Skyway Security, Mauldin, South Carolina) recorded behavior in each group 24-hours a day over 14 consecutive days. Cameras were focused on the holding area in front of the AMS, the AMS itself, and the AMS exit and entrance alleys and gates. Individual cows were identified on video by matching their unique spot patterns to a picture database containing photos of each cow's head, rear, right and left sides.

Inter-observer Reliability

Three individuals extracted data from the pre-recorded video. In order to assess the reliability of the data being collected between individuals, identical video clips were decoded before the start of the trial and during the middle of data collection by each individual. Identical measurements were recorded and analyzed for similarity between individuals.

AMS Exit Duration

Behavioral observations were made of each visit a cow made to the milking stall. The type of visit (unsuccessful or successful) was noted, and the time taken for the cow to exit the AMS milking stall (i.e., duration of time from start of AMS exit gate opening to the time of exit gate closing behind focal cow) was recorded. Additionally, circling (i.e., focal cow exited the alley, then made successive attempt(s) to re-enter the AMS) was recorded if applicable.

Hesitation & Blocking Events

Video of cows exiting the AMS was observed to describe the flow of cow traffic in the exit area. Observation began after the exit gate of the milking stall closed behind the focal cow. Cows that paused (i.e., stood still for greater than 3 seconds) in the exit the alley were identified as "hesitators", and the duration of hesitation (in seconds) for each event was recorded. Cows that stood in the holding area at the exit alley one-way gate and prevented cows in the exit alley from leaving (either passively or actively) were identified as "blockers". Observers recorded the identity and number of cows located in the holding area as the focal cow exited the AMS. Specific locations of the cows in the holding area were noted. Information on individual cow characteristics (stage of

lactation, parity, presence and positioning of horns, and milk yield) was utilized during statistical analysis for evaluation of possible predictors for cows that hesitated or blocked.

Time Budget of the AMS

Durations were recorded for successful milking events ((SM): cow enters the AMS and is milked), unsuccessful milking events ((UM): cow enters the AMS but an inefficient amount of time had elapsed since the last milking and she is released without milking), robot cleaning events ((RC): AMS is unavailable for entry due to cleaning), robot empty events ((RE): AMS is available for new cow entry, but remains vacant), and back-up events ((BU): blocking event escalates until most recently milked cow cannot exit AMS; AMS is unavailable for new cow entry). Durations of each event were summed to create total durations for each event type for each 24 hour period for a total of 14 days. When applicable, the identity of cows involved in each event (SM, UM, and BU) was noted.

Statistics

All analyses of the data were conducted using SAS v.9.1.3 (Statistical Analysis Software, Cary, NC). When appropriate, results were reported as least square means ± standard error of the mean (SEM). Results were considered statistically significant at a probability of α less than 0.05.

Inter-observer Reliability

Analyses of the data were conducted with the REG procedure to calculate Spearman's coefficient of correlation in order to determine the reliability of measurements collected by individuals. The accuracy between individuals was determined using the correlation coefficient value for the two individuals in question.

AMS Exit Duration

Analyses of the data were conducted with the MIXED and GLIMMIX (using the ODDS RATIO option) procedures. Data were log transformed to fit the assumptions of normality. To determine if the type of visit to the AMS (UM or SM) predicted the duration of time to exit the AMS, the following mixed linear model was used (SAS, Proc MIXED):

$$(\log_{10})Y_{ijk} = \mu + D_i + G_j + V_k + e_{ijk}$$

Where:

$Y_{ijk} =$ duration of time to exit AMS (continuous);

$\mu =$ overall mean;

$D_i =$ random effect of day (i = 0 to 13 days);

$G_j =$ fixed effect of group (j = 2 groups);

$V_k =$ visit type (k = 2 visit types (UM or SM)); and

$e_{ijk} =$ residual error.

The probability that UM resulted in a cow circling and re-entering the AMS was investigated using the following logistic regression model to determine an odds ratio (Proc GLIMMIX):

$$\log_{10}(P_{\text{unsuccessful milking}}/1\text{-}P_{\text{unsuccessful milking}}) = \alpha + \beta * C_i + e_i$$

Where:

$\alpha =$ log of odds ratio of unsuccessful visit vs. successful visit under the condition that cow didn't circle ($C_i = 0$) or did circle ($C_i = 1$);

$\beta =$ log of odds ration of unsuccessful visit vs. successful visit $- \alpha$;

$C_i =$ instances of circling (i = 2 types of events (circle, not circle)); and

$e_i =$ residual error.

Hesitation Events

Analyses of the data were conducted using the MIXED procedure for both of the following models. In both instances, data were log transformed to fit the assumptions of normality. The effect of cows present in the general holding area or cows blocking the end of the exit alley on the duration of hesitation was analyzed using the following mixed linear model:

$$(\log_{10})Y_{ijk} = \mu + D_i + G_j + A_k + e_{ijk}$$

Where:

$Y_{ijk} =$ duration of hesitation (continuous);

$\mu =$ overall mean;

$D_i =$ random effect of day (i = 0 to 13 days);

$G_j =$ random effect of group (j = 2 groups);

$A_k =$ area of cow location (k = 3 locations (holding area, end of exit alley, no cows present));

and

$e_{ijk} =$ residual error.

The following mixed linear model was used to determine the effect of the number of cows in the holding area on the duration of hesitation:

$$(\log_{10})Y_{ijk} = \mu + D_i + G_j + N_k + e_{ijk}$$

Where:

$Y_{ijk} =$ duration of hesitation (continuous);

$\mu =$ overall mean;

$D_i =$ random effect of day (i = 0 to 13 days);

$G_j =$ random effect of group (j = 2 groups);

N_k = number of cows in holding area, including the end of the exit alley (k = 1 to 5 cows); and

e_{ijk} = residual error.

Hesitating Cow Characteristics

Analyses of the data were conducted using the GLIMMIX procedure (using the ODDS RATIO option). The influence of stage of lactation was investigated with respect to the number of times cows hesitated for long periods (>500 seconds). Weight of the cow, parity, horn positioning and milk yield were removed from the model when determined to not be significant ($P > 0.05$). The following logistic regression model was used:

$$(P_{hesitation}/1\text{-}P_{hesitation}) = \alpha + \beta*L_i + e_i$$

Where:

α = odds ratio of hesitation (>500 seconds) vs. no hesitation under the condition that cow was in early, mid, or late lactation;

β = odds ration of hesitation (>500 seconds) vs. no hesitation – α;

L = stage of lactation (i = 1 to 3 stages

(early (<100 DIM), mid (101-200 DIM), late (>200DIM))); and

e_i = residual error.

Blocking Cow Characteristics

Analyses of the data were conducted using the GLIMMIX procedure. The influence of weight, parity, stage of lactation, presence and positioning of horns, and milk yield were investigated for cows that frequently blocked ($\geq$ 15 blocking events in a fourteen day period, i.e., >1 times per

day), cows that occasionally blocked (7 - 14 blocking events in a fourteen day period, i.e., 0.5 – 1 times per day) and cows that almost never blocked (0 - 6 blocking events in a fourteen day period, i.e., <0.5 times per day). Stage of lactation, presence and positioning of horns, and milk yield and their interactions were removed from the model when determined to not be significant ($P > 0.05$). The following mixed linear model was used (description of incidences below pertains to both of the following models):

$$Y_{ijk} = \mu + G_i + P_j + W_k + P_j*W_k + e_{ijk}$$

To determine if parity had an effect on weight (i.e., to determine if the two variables were auto-correlated), the following model was used with Proc MIXED:

$$W_{ijk} = \mu + G_i + P_j + e_{ijk}$$

Where:

$Y_{ijk} =$ blocking category (0 or 1);

$\mu =$ overall mean;

$G_i =$ random effect of group (i = 2 groups);

$P_j =$ parity of the cow (j = 2 levels (primiparous, multiparous));

$W_k =$ weight of cow in lbs (k = continuous measure); and

$e_{ijk} =$ residual error.

Upon further investigation of the data set, cows that frequently and occasionally blocked were combined into one category to better balance the number of cows in each category (n=50 never block, n=34 occasionally and frequently block).

AMS Time Budget

Analyses of the data were conducted with the CORR procedure to calculate Pearson's coefficient of correlation in order to determine the relationship between events of interest over a 14 day period. Back-up events (BU) and unsuccessful milking (UM) events were evaluated to determine their relationship with successful milking (SM) events. Additionally, the relationship between robot empty events (RE) and back-up events was investigated. Statistical significance was declared when the correlation coefficient between each pair of the variables was at a probability of α less than 0.05, indicating dependence between the two events in focus. The strength of the relationship was determined using the correlation coefficient value for each two events in question.

Inter-day variability

Analyses of the data were conducted with the MIXED procedure in SAS v.9.1.3 (Statistical Analysis Software, Cary, NC) to evaluate potential variability among days for each of the five events investigated (BU, SM, RE, RC, UM). Statistical differences were based on the least squares means of day for SM, UM, and RE when differences were significant at a probability of α less than 0.05. The following mixed linear model was used:

$Y_{ij} = \mu + G_i + D_j + e_{ij}$

Where:

$Y_{ij} =$ Event of interest (BU, SM, RE, RC, UM);

$\mu =$ overall mean;

$G_i =$ random effect of group (i = 2 groups);

$D_j =$ repeated measure of day (j = 0 to 13 days); and

$e_{ij} =$ residual error.

RESULTS

Inter-observer Reliability

Greater than 85% reliability was reached between individuals prior to the start of and mid-way through data collection (Watkins and Pacheco, 2000).

AMS Exit Duration

Cows that had an unsuccessful milking experience exited the AMS more slowly (18.2 ± 1.04 seconds) than those who had experienced a successful milking event (16.2 ± 1.03 seconds; $P < 0.01$). In addition, there was a higher probability that cows would circle the milking stall after an unsuccessful visit (0.8 ± 0.15), compared to a successful one (0.2 ± 0.03).

Hesitation Events

Cows hesitated for a longer period of time in the exit alley after visiting the AMS if there was another cow blocking her exit at the other side of the one-way exit alley gates (192.93 ± 1.11 seconds) than if there were no cows present in either the holding area or at the one-way gates (88.11 ± 1.07 seconds; $P < 0.001$). Additionally, cows hesitated longer in the exit alley if there were cows located in the general holding area (101.04 ± 1.07 seconds) than if there were no cows present (83.66 ± 1.08 seconds; $P < 0.001$). There was a positive relationship between the number of cows in the holding area and the duration of hesitation in the exit alley ($P < 0.001$; Figure 3.3). While highly variable, the data indicate that as the number of cows in the holding area increased, the duration of hesitation for cows exiting the alley also increased (Figure 3.3).

Figure 3.3: The duration of hesitation for cows exiting the alley is related positively to the number of cows located in the holding area ($P < 0.001$).
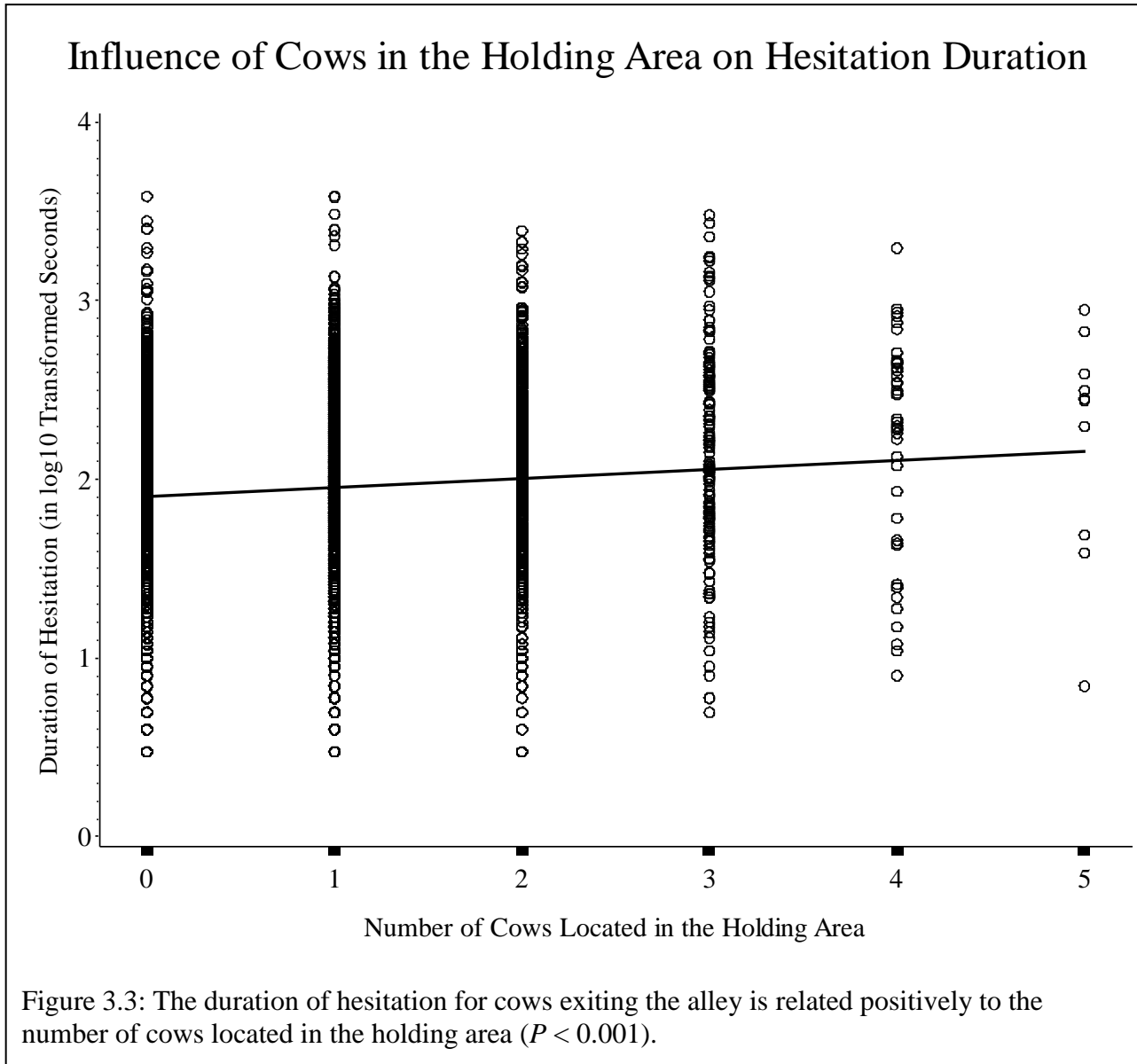
Hesitating Cow Characteristics

Stage of lactation was a predictor of cows that hesitated for long periods (>500 seconds) in the exit alley ($P < 0.01$; Figure 3.4). The average successful milking event occurred for 449 seconds (calculated as time of entry into milking stall to start of exit from stall), therefore 500 seconds was chosen to represent a potentially debilitating hesitation period. If a cow is still standing in the exit alley when a recently milked cow tries to leave the milking stall, there is a greater potential for a back-up event in which the AMS cannot accept the next cow for milking.

Influence of Stage of Lactation on Hesitation Duration

Figure 3.4: Late lactation cows (0.55 ± 0.096) and mid lactation cows (0.36 ± 0.1) had a greater probability than early lactation cows (0.15 ± 0.07) of hesitating for periods longer than 500 seconds (Early Lactation: n=31; Mid Lactation: n=27; Late Lactation: n=42).
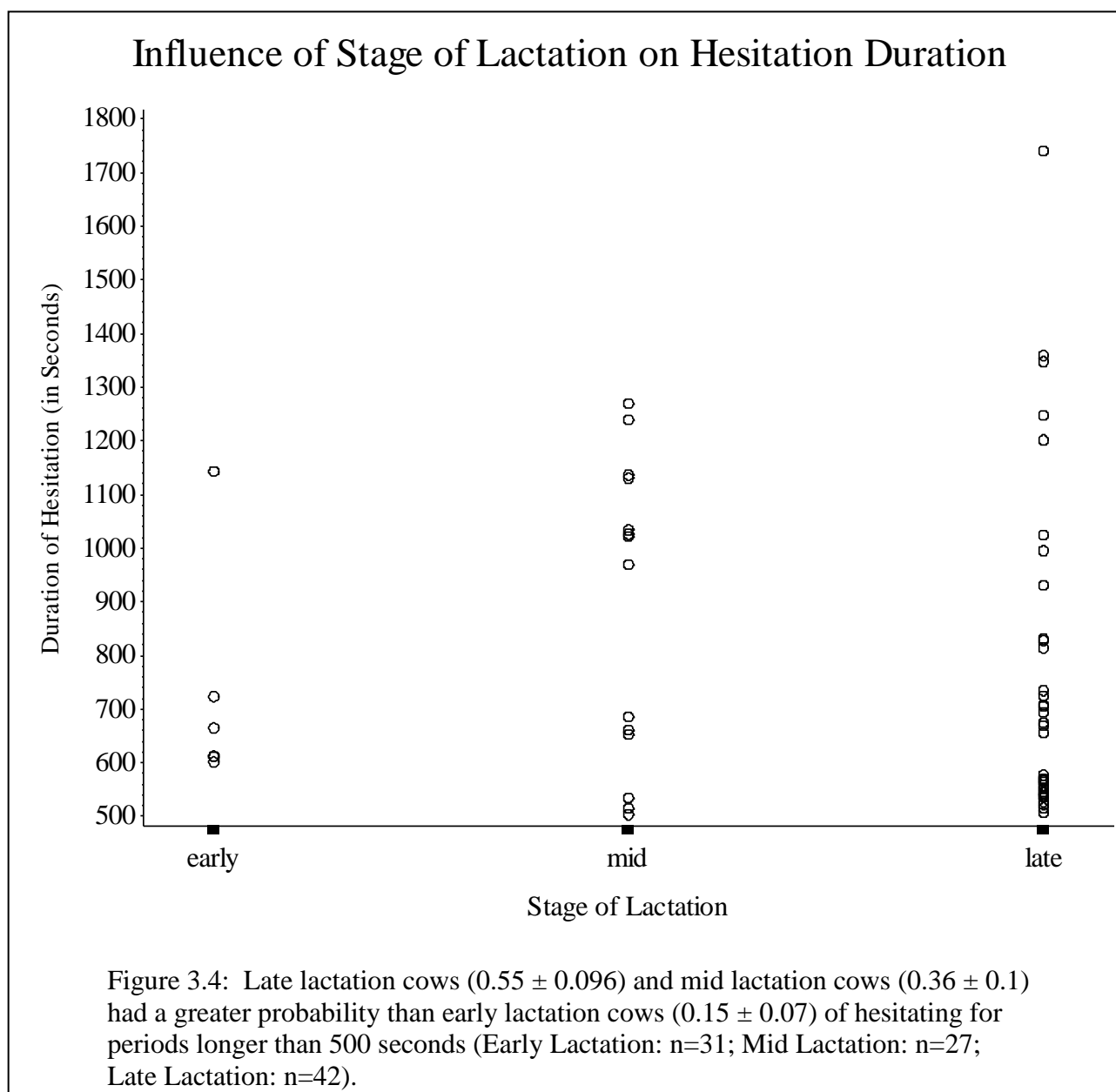
Blocking Cow Characteristics

Parity was a factor that influenced frequency of cows blocking other cows from leaving the AMS exit alley ($P < 0.05$). Primiparous cows had a greater probability of being frequent blockers, compared to multiparous cows ($P < 0.05$). In addition, weight had an influence on blocking grade ($P < 0.05$), with lighter-weight cows being more likely to block than heavier-weight cows. However, as expected, multiparous cows were typically heaiver (1414.04 ± 18.12 pounds) than primiparous cows

(1239.18 ± 25.41 pounds; $P < 0.001$), suggesting the variables of weight and parity to be auto-correlated. When weight and parity were analyzed in the same model, parity appeared to be the more significant factor influencing the likelihood that a cow would block.

Time Budget of the AMS

There was no relationship between unsuccessful and successful milking events for either group 1 or group 2 ($r = 0.22$, $P = 0.42$; $r = 0.26$, $P = 0.34$, respectively; Figure 3.5). There was no relationship between successful milking and back-up events in group 1 ($r = 0.01$, $P = 0.69$); however, there was a trend towards a negative relationship for these two events in group 2 ($r = -0.49$, $P = 0.07$; Figure 3.6). There was a negative relationship between AMS empty and back-up events in group 1 ($r = -0.74$, $P < 0.01$); however, no such relationship between the two events was determined in group 2 ($r = -0.14$, $P = 0.61$; Figure 3.7).

Figure 3.5: The relationship between successful and unsuccessful milking events was not significant in group 1 (r=0.22, p=0.42) or group 2 (r=0.26, p=0.34).
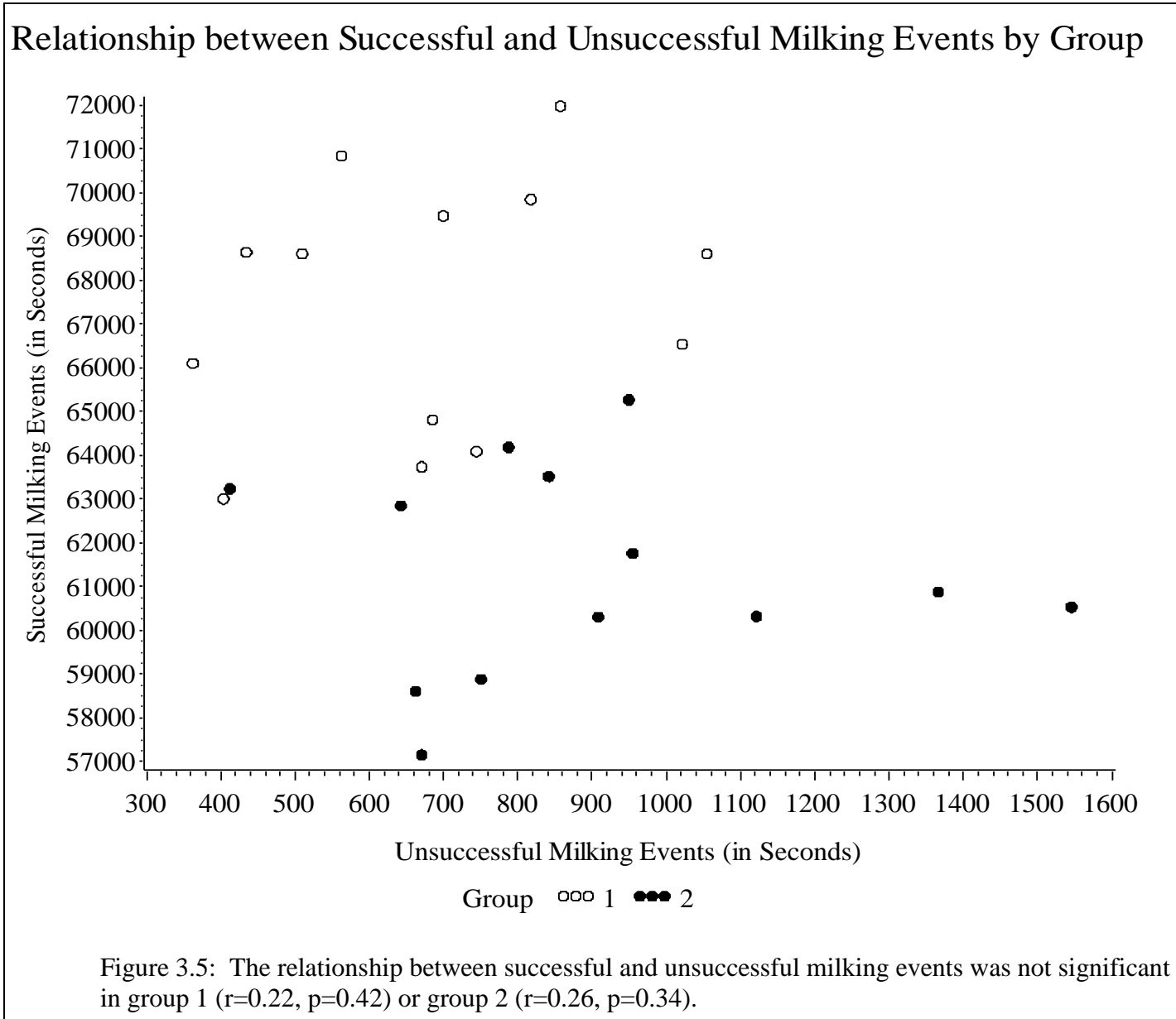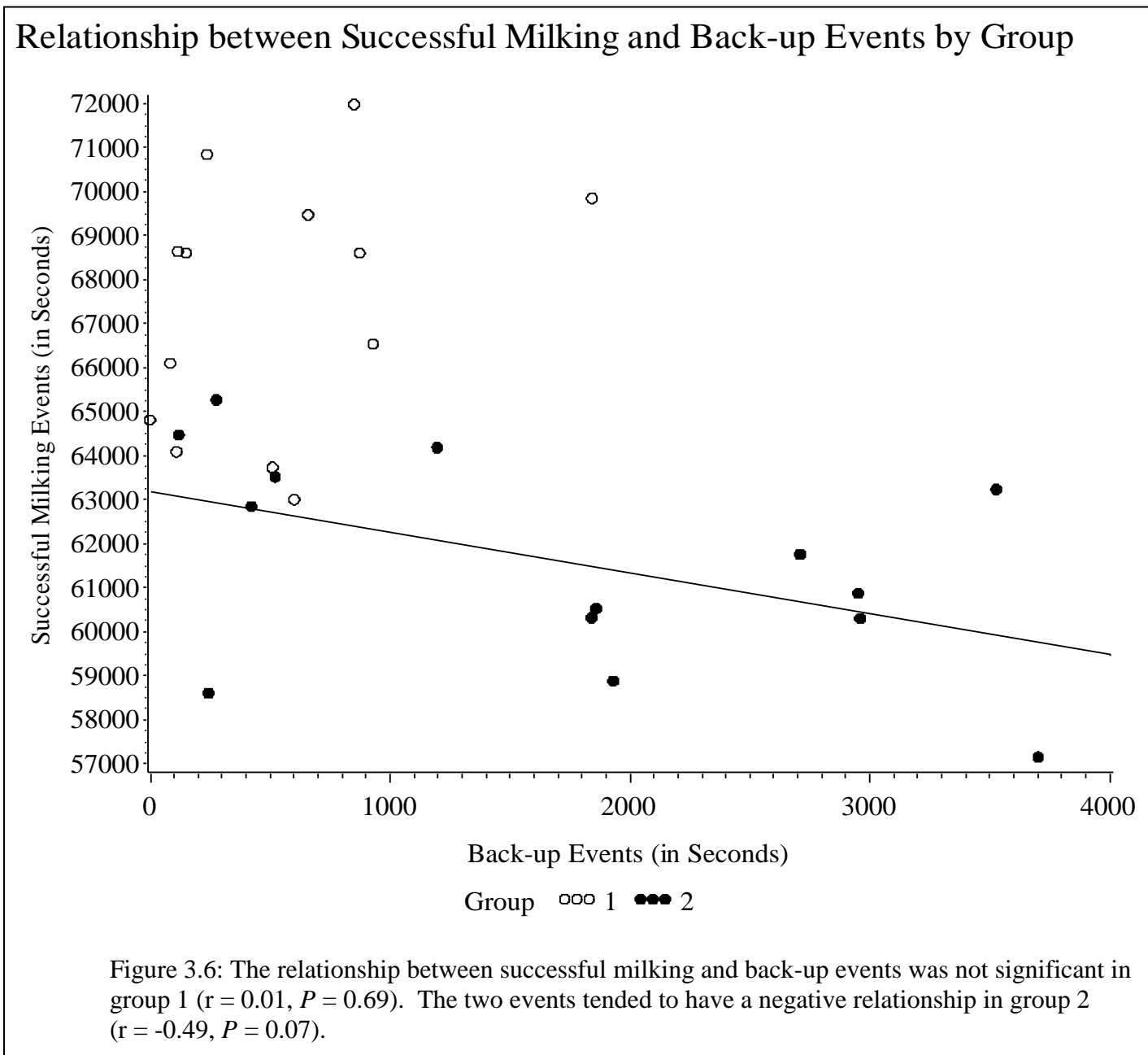
Relationship between Successful Milking and Back-up Events by Group

Successful Milking Events (in Seconds) vs Back-up Events (in Seconds)

Group ○○○ 1 ●●● 2

Figure 3.6: The relationship between successful milking and back-up events was not significant in group 1 (r = 0.01, P = 0.69). The two events tended to have a negative relationship in group 2 (r = -0.49, P = 0.07).
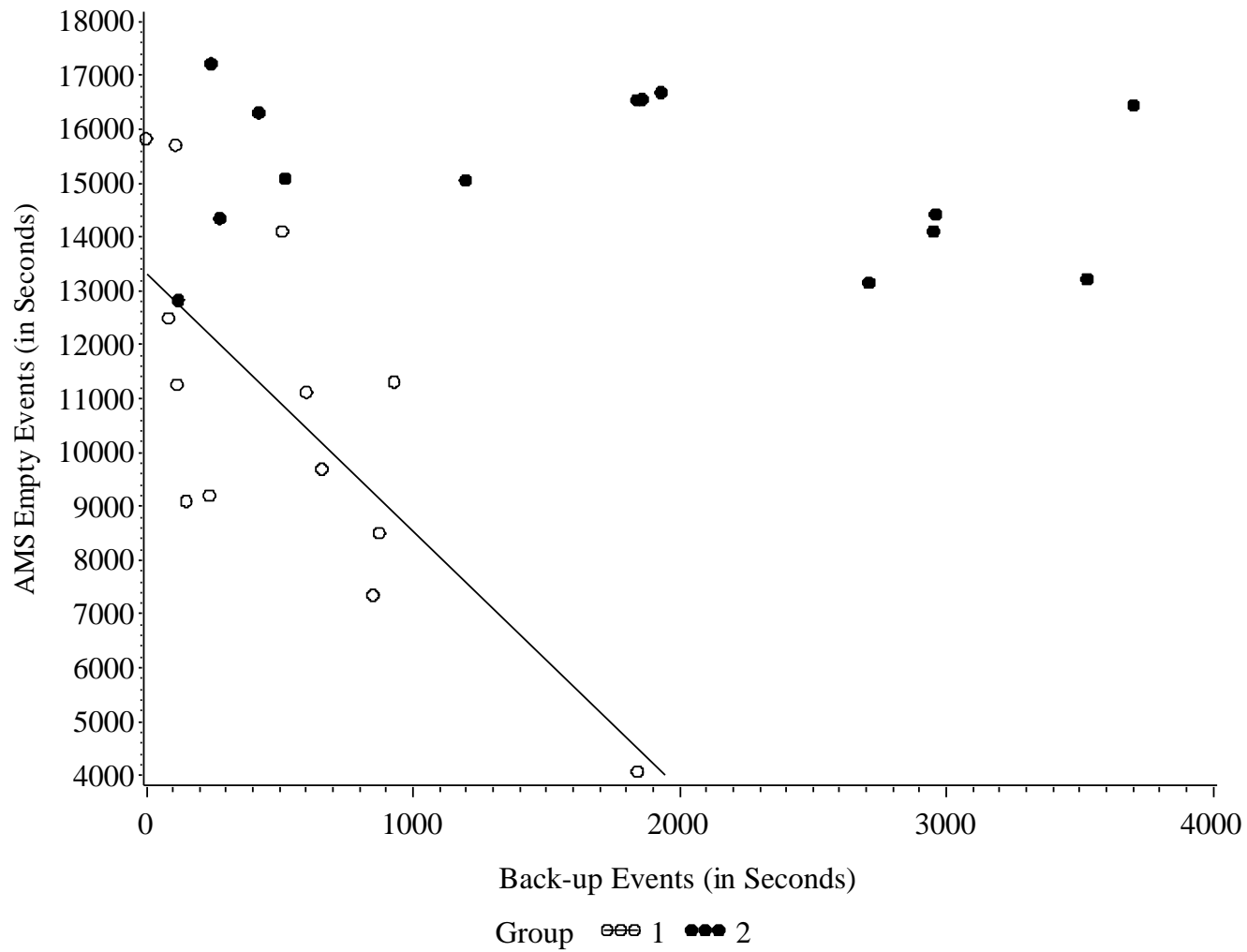
Figure 3.7: A negative relationship between AMS empty and back-up events were observed in group 1 (r = -0.74, $P < 0.01$). No relationship existed between the two events in group 2 (r = -0.14, $P = 0.61$).

Inter-day variability

The duration of SM, RE and UM events varied significantly across days over the 14-day period examined ($P < 0.05$). However, the duration of BU events ($P = 0.24$) and RC events ($P = 0.93$) remained consistent across the days of the study. Figure 3.8 depicts the average percentage of time the events of interest occurred over a 24-hour period in each group (14 days total).

Mean Time Budget in the AMS by Group

Figure 3.8: Average percentage of time for each event (Back-up (BU; 1%), Robot Cleaning (RC; 5%), Robot Empty (RE; 14%), Successful Milking (SM; 78%), and Unsuccessful Milking Events (UM; 2%)) across both groups over a 24-hour period.
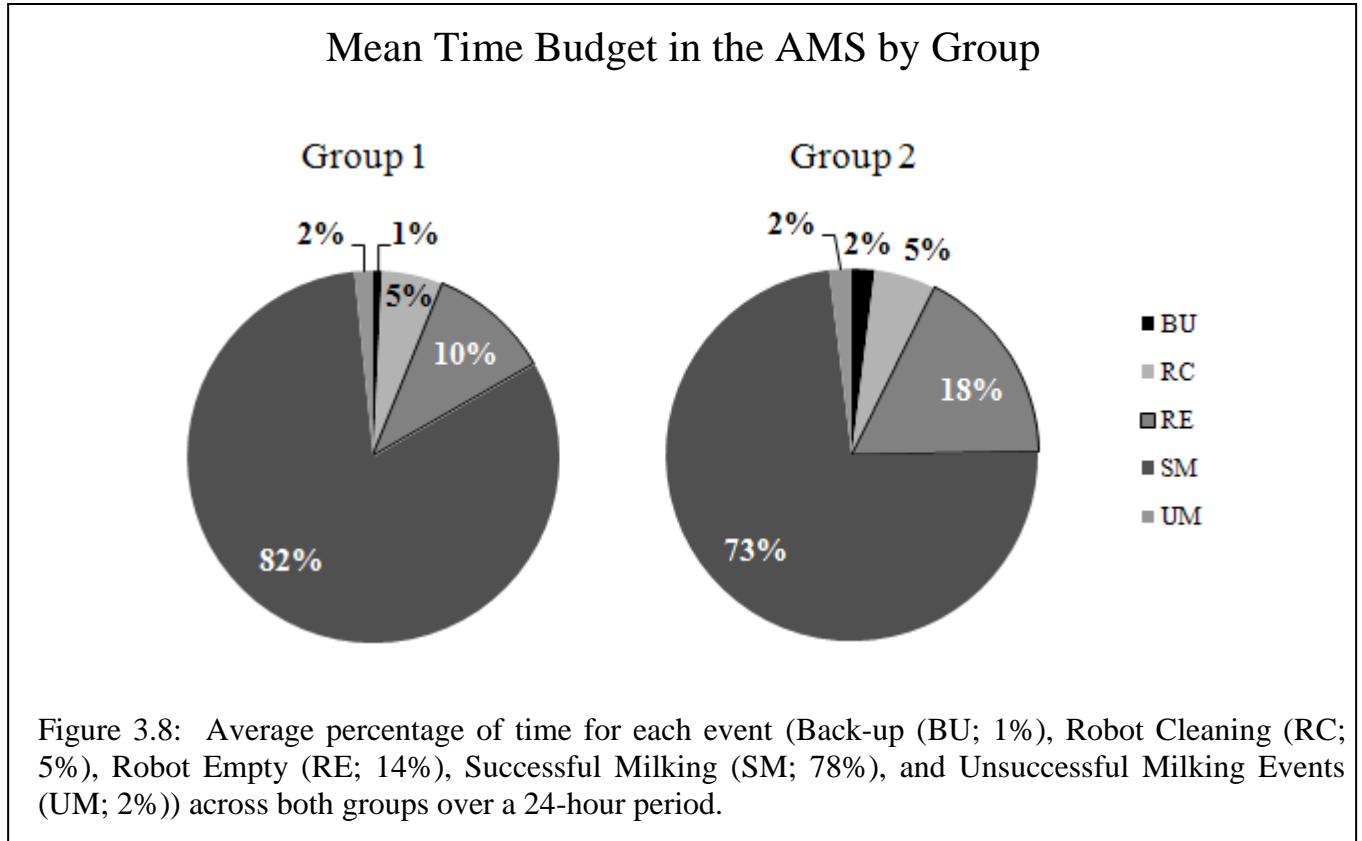
DISCUSSION

AMS have the potential to increase milk production when compared to parlor systems that milk cows twice daily (de Koning et al., 2002; Rotz et al., 2003; Wade et al., 2004). However, the number of milking events achieved per cow per day in an AMS can vary, and is dependent upon individually set milking intervals for each cow, a cow's motivation to access the milking stall, cow traffic through the barn, and the frequency with which farm staff fetches overdue cows. It is important that the AMS operates in an efficient manner so that each cow can achieve at least her designated number of milking events each day and, in turn, produce the maximum amount of milk possible. Any factors resulting in a potential decrease of AMS efficiency should be examined. General cow traffic patterns throughout the barn, comfort during milking, and motivation to access the milking stall have been investigated for their ability to achieve the desired number of milking visits (Stefanowska et al., 1999; Melin et al., 2006; Rousing et al., 2006; Bach et al., 2007; 2009). However, specific configurations of gates and alleys that control traffic through and around the AMS have not yet been investigated in depth. These gates and alleys have the potential to influence the number of milking events achieved, and thus should be considered when installing an AMS and developing the ideal surrounding area. Additionally, cow behavior has the potential to contribute to AMS efficiency, as milking events are no longer achieved by human scheduling and interference. For this reason, cow behavior and its interaction with gate and alley design was investigated in this study and the resulting availability of the AMS was estimated. It should be noted that this system was not milking to capacity (with only 42 cows/AMS), and thus these results may underestimate the effect that hesitation and blocking events could have in a system that is milking at or near capacity.

Unsuccessful milking events previously had been related to cows exiting the milking stall more slowly compared to cows that had experienced a successful milking event (Stefanowska et al., 1999). Our study yielded similar results. One of the key factors motivating cows to access the milking stall is the offer of concentrate upon entry (Prescott et al., 1998). It is probable that cows entering the milking stall expected to receive a concentrate reward regardless of whether or not they were milked. The additional time taken to exit the milking stall by UM cows may have been a reflection of the cows' expectation to receive feed upon arrival, and reluctance to leave when the predicted event did not occur. Furthermore, cows that had experienced an unsuccessful milking event were more likely to circle and return immediately to the AMS compared to cows that experienced a successful milking event, as a probable result of the expectant concentrate reward. Under these circumstances, unsuccessful milking events may be described as being inefficient; additional time spent exiting the milking stall coupled with successive circling events waste AMS time and may deter or delay cows that are waiting and ready to be milked.

The presence of cows in the holding area and in the area behind the one-way exit alley gates encouraged longer bouts of hesitation in the exit alley by cows leaving the AMS. These results agree with those of Stefanowska and colleagues (1999) who described similar effects. More specifically in this experiment, a positive relationship was determined to exist between the number of cows located in the holding area and the duration of hesitation by a cow in the exit alley. This suggests that a balance must be achieved in the holding area. Certainly the objective of the holding area is to encourage new cow approach for milking events by providing a large area for a cow queue. However, cows lingering unnecessarily in the holding area, particularly if they are affecting the behavior of cows attempting to access or exit the system, could reduce efficiency of the AMS.

Hesitation events still occurred frequently even when no cows were present in the holding area or directly in front of the exit alley gates. Cows in late and mid lactation were more likely to hesitate in the exit alley for longer periods compared to those in early lactation. Late lactation cows were most likely to hesitate for periods longer than 8 minutes in the exit alley. Early lactation cows have been suggested to adopt a more efficient feeding strategy to support a higher milk yield, and thus may have been more eager to enter the feeding alley after milking (Cooper et al., 2010). Winter and Hillerton (1995) reported the slowest (and also oldest) cow in their experimental group took an average of 7.03 minutes to exit the area around the AMS; however, their observational group included early lactation cows only. Age or parity did not have an effect on the duration of hesitation in our experiment.

Parity was determined to be a predictor of cows that blocked the exit alley. Furthermore, an interaction between parity and weight was determined; more specifically primiparous, lighter-weight cows were more likely to be blockers than heavier primiparous cows. Lighter, primiparous cows have been suggested to be subordinate to their heavier, multiparous herd mates (Bouissou, 1972; Phillips and Rind, 2001) and thus would not be expected to be successful blockers, as forcing another cow to stop walking would seem to require a social advantage on the part of the blocker. However, the design of the gates around the AMS may have provided these lower-ranking cows with physical barriers that allow them to block. It has been suggested that animals value resources differently, and dominance relationships change depending on the resource (Val-Laillet et al., 2008). Thus, there is a possibility that the lighter-weight primiparous cows (assumed to be lower-ranking) block others as a means to improve their status, and subsequent access to the milking stall. Alternatively, one study suggests that the degree of aggressiveness (measured by the number of active aggressive interactions initiated by an

individual), rather than the weight or parity of the cow, is more often a predictor of dominance (Collis, 1976). As the degree of aggressiveness was not something determined for cows in this study, it may be another predictor for blocking that was not considered.

Unsuccessful milking events did not appear to share any relationship with successful milking events in the cows investigated. However, the two groups did exhibit differences in relationships between certain events of interest. Back-up events shared a weak negative relationship with successful milking events in group 2, but no such relationship was observed for cows in group 1. Furthermore, AMS empty events shared no relationship with back-up events in group 2; however, the two events did share a negative relationship in group 1. The AMS in group 2 was empty an average of 18% of the day, and it was possible that time spent in back-up events could be absorbed by the available AMS empty time, resulting in a lack of relationship with successful milking events. However, in group 2, with the AMS empty only 10% of the day, no such relationship existed between the time spent in back-up events and AMS empty events. Ideally, back-up events would be absorbed by available empty events, as observed in group 1; however, the overall results suggest that an undesirable alternative is possible.

The difference between groups was unexpected and subsequently difficult to interpret. There were, however, several numerical differences for the events of interest between the two groups that may have influenced the results. Group 2 had numerically higher values of back-up events, AMS empty events, and lower values of successful milking events compared to group 1 (Appendix C). It is possible that these numeric differences had an effect on the subsequent relationships determined between the events of interest. Neither AMS milking unit was being used to capacity, with an experimental group size of 42 cows per AMS instead of the frequently recommended 60 cows per AMS, which may have allowed for greater flexibility in time budgets.

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Additionally different social dynamics between the groups, or the influence of one or more specific cows within the groups may have resulted in variable time budgets of the AMS units between the two groups. It will be important for future research to determine if back-up events generally share a relationship with the amount of time spent successfully milking or with robot empty time, particularly in AMS that are used to capacity. Perhaps even when at capacity, different social dynamics within groups of cows will prove to have the largest influence on AMS time budgets. The AMS has been developed in part to give the cows more control and flexibility in their environment, and a less predictable operation may be the result.

CONCLUSION

In conclusion, there are a number of factors that may affect the availability of an AMS. Cow behavior as well as gates and alleys that control cow traffic around the AMS may have more influence on AMS availability than previously thought. However, future research examining AMS units being used to capacity may be worthwhile. This research includes only one experimental herd and barn design, and thus provides a very specific description of events. In the future, an inclusion of numerous experimental herds, facility designs, and differing group sizes may help lead the industry to an ideal gate and alley configuration to promote optimum availability of the AMS for successful milking events.

CHAPTER 4

SUMMARY AND CONCLUSIONS

The overall goal of this thesis research was to gain further insight into the interaction between cows and an AMS environment, specifically adaptation to the milking stall and the effects that cow behavior and gate and alley configuration surrounding the AMS milking stall have on its availability for milking. The aim of the first study was to investigate the length of time cows required to adapt to milking in a newly introduced AMS. We hypothesized that cows would gradually adapt to the milking process over time, and would subsequently show less frequent stress-related behaviors each day. The sharp decline in the stress-related behaviors of urination, defecation, and vocalization suggests adaptation to the new milking process took place within 24 hours after transitioning. Further supporting the rapid adaptation rate, average milk yield rebounded following day 0. These results suggest that cows were initially stressed on the day they transitioned to the new milking process and environment; however, they adapted to the new situation within 24 hours.

In this study, there was a tendency towards an increase in stepping and kicking behavior following teat cup attachment between day 0 and day 32. Stepping and kicking behavior has been linked to discomfort during the milking process. It is possible that the increase in stepping and kicking behavior was caused by discomfort or novelty related to the new milking process. Teat cup liners were new and pulsation ratios were different than what cows previously had been milked with, and it is possible that teat end condition deteriorated during the first month. No inspection of teat ends occurred at the time, and therefore this speculation is impossible to verify or reject. Alternatively, the increase in stepping and kicking behavior may have been a reflection of the cow's learning to predict when their release from the milking stall was about to occur.

Regardless of the reason for increased stepping and kicking behavior, the cows appeared to reliably access the milking stall on their own accord by the end of the experimental period. On day 32, fewer than 5% of the cows needed to be brought to the milking stall by the stock people. This is worthwhile information for farmers considering switching from a conventional parlor milking system to an AMS; after one day, cows appear to adapt to milking with the new system, and after one month, nearly all cows appeared to be comfortable approaching and entering the milking stall without human assistance.

The aim of the second study was to interpret how cow behavior and interaction with the gate and alley configuration near the milking stall affected the availability of the AMS. One of the main purposes of the AMS is to decrease farm labor during the milking process. The AMS accomplishes this task through both automated milking and gate and alley configurations that should promote smooth flow of cow traffic around and through the AMS.

Our results indicated that cows that had experienced an unsuccessful milking visit exited the AMS more slowly relative to cows that had experienced a successful milking visit. Additionally, these unsuccessful cows were more likely to circle the AMS and enter again. Under these circumstances, unsuccessful milking visits create inefficiencies associated with the AMS. Cows waiting to legitimately access the AMS may be either unable to enter the milking stall, or discouraged from approaching the area when a circling cow present. In addition, the presence of cows in the holding area and blocking the one-way gates in front of the exit alley had a negative effect on the duration of time required for the cow to exit the milking stall. Furthermore, our results indicated that as the number of cows in the holding area increased, the exiting cow's duration to exit increased. This suggests the importance of achieving a balance in the holding area; cows need to be motivated to visit the AMS on their own accord, however, they

should also be encouraged to leave the area once they have visited to avoid having a negative effect on others.

The contradicting results for AMS time budgets between the two experimental groups suggest that the relationships between events of interest may be more complex than previously thought. The AMS offers more control and flexibility over the cow's environment (particularly when associated with free cow traffic) compared to traditional parlor systems. The relationships between different events are likely associated with and dependent on the behavior of individual cows, and subsequent social dynamics of the experimental groups. This situation may have been exacerbated in our experimental herd, as neither AMS group was milking to capacity; potentially resulting in greater flexibility for each group's time budgets and relationships between events of interest.

These results provide important insight to the dairy industry, particularly those considering incorporating an AMS into their farm. The results from the first study suggest that cows adapt relatively quickly when transitioning from a conventional parlor system to an AMS; however, variables associated with milking may need to be examined more closely for sources of discomfort or novelty. In addition, farmers may be able to expect a voluntary approach rate of 95% within the first month of transitioning. The results from the second study indicate that cow behavior has an effect on the availability of the AMS. The gate and alley configuration at this experimental farm, despite following many current industry recommendations, appeared to be flawed as it allowed for blocking behavior and other inefficiencies to occur around the AMS; although the degree to which these situations affect the availability of the AMS may be variable between farms, potentially dependent on the number of cows accessing the system, and group social dynamics. Anecdotally, similar situations involving cow blocking and back-up behaviors

have been reported by individuals within the dairy industry. Further research should be conducted on a variety of layouts near the milking stall to determine a solution to encourage efficient cow traffic flow around the AMS.

APPENDICES

APPENDIX A

LELY START-UP PROCEDURE

Lely Start-up Procedure* (2009)

**Start-up:
Day 0**

Phase 1:
1. Divide each group into two sub-groups: see area A and B in diagram below
2. Start milking the cows from area B1 to B2
3. Leave the cows in area A to rest. This group has access to free stalls, feed bunk, and water
4. After each cow from area B1 is milked, they are moved to area B2
5. After all cows from area B1 have been milked and moved to area B2, bring cows from area A into area B1
6. The cows from area B2 can rest in area A
7. Repeat this process so that cows are milked three times a day

When 75% of the herd is accessing the robot without assistance, move to Phase 2

**Phase 2:
Day 3**

Phase 2:
1. Remove all gates and make it one herd again
2. Check 4 times a day the attention list: 'Too late for milking'
3. Bring the cows with more than 10 hours since last milking to the robot

When the herd has reached 2.5 milkings per cow per day, move to Phase 3

**Phase 3:
± Day 14**

Phase 3:
1. Check 3 times a day the attention list: 'Too late for milking'
2. Bring cows with more than 12 hours since last milking to the robot

When 95% of the herd is accessing the robot without assistance, move to Phase 4

**Phase 4:
± Day 60**

Phase 4:
1. Check 2 times a day the attention list: 'Too late for milking'
2. Bring cows with more than 12 hours since last milking to the robot

Figure 4.1: This was the start-up procedure recommended by the Lely consultants, and goals to reach specific phases were approximate. For example, the KBS herd reached Phase 2 by Day 2, and Phase 4 by Day 32.

Temporary Cow Traffic during the Start-up Procedure
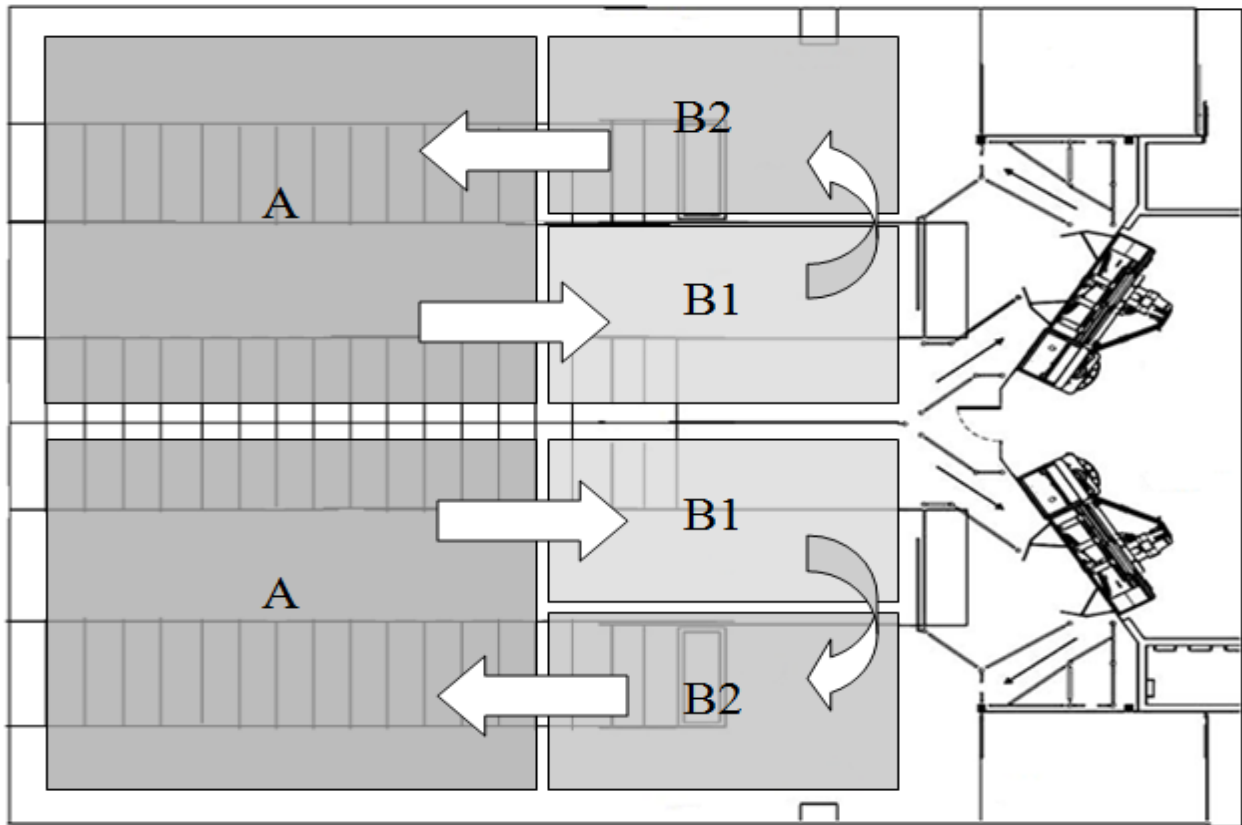
Figure 4.2: Temporary gates split each group within the herd into two main areas (A & B) for training during the start-up procedure on Days 0-3. Cows are moved from area B1 to be milked in the robots, and moved to area B2 after milking. Cows in area A are at rest. Once all cows have milked and moved to area B2, they are moved into area A. Cows previously in area A are moved into area B1 for milking. This is repeated three times daily to achieve 3x milkings per day.

APPENDIX B

COUNT OF BLOCKING EVENTS DURING THE 14-D EXPERIEMENTAL PERIOD

Count of Blocking Events during the 14-d Experimental Period

Group 1			**Group 2**		
Cow #	**Parity**	**# Blocks**	**Cow #**	**Parity**	**# Blocks**
2127	M	1	2140	M	5
2133	M	8	2141	M	10
2152	M	7	2224	M	7
2238	M	4	2401	M	13
2240	M	5	2403	M	3
2313	M	1	2404	M	8
2416	M	3	2408	M	2
2417	M	2	2411	M	8
2422	M	5	2415	M	1
2503	M	20	2418	M	20
2504	M	3	2502	M	1
2505	M	6	2511	M	1
2506	M	5	2515	M	2
2508	M	3	2525	M	12
2514	M	4	2529	M	10
2516	M	4	2531	M	3
2524	M	1	2535	M	30
2527	M	2	2536	M	2
2537	M	2	2543	M	3
2604	M	3	2544	M	1
2618	M	1	2603	M	1
2619	M	8	2608	M	1
2622	M	4	2613	M	2
2627	M	4	2616	M	8
2628	M	19	2621	M	11
2632	M	13	2624	M	2
2635	M	5	2626	M	16
2706	P	7	2631	M	8
2715	P	2	2634	M	5
2717	P	4	2703	M	4
2722	P	1	2709	P	8

Table 4.1 continued

2723	P	16		2719	P	8
2724	P	87		2720	P	31
2726	P	43		2721	P	5
2727	P	4		2722	P	11
2729	P	13		2728	P	6
2733	P	7		2730	P	19
2734	P	6		2731	P	24
2735	P	27		2738	P	3
2737	P	30		2740	P	22
2802	P	18		2801	P	16
2803	P	17		2804	P	11
Total		425		2805	P	1
				2811	P	39
				Total		404

Table 4.1: Total number of blocking events for each individual cow during the 14 day experimental period ((P) primiparous; (M) multiparous). The number of blocking events varied greatly between cows; cows with the fewest number of blocking events exhibited this behavior once in a 14 day period, and the cow with the greatest number of blocking events exhibited this behavior 87 times in a 14 day period.

APPENDIX C

DURATION OF SUCCESSFUL MILKING AND BACK-UP EVENTS DURING THE 14-D
EXPERIMENTAL PERIOD

Duration of Back-up Events during the 14-d Experimental Period

	Day						
Group	0	1	2	3	4	5	6
1	601	0	85	511	930	7581	1843
2	522	244	1932	1861	1841	2711	121
	Day						
Group	7	8	9	10	11	12	13
1	111	117	660	875	151	238	851
2	3703	2953	2961	3529	423	277	1198

Group	14-day Average
1	1039.5
2	1734

Table 4.2: Total duration of back-up events (in seconds) during each day of the experimental period. Back-up events varied greatly between days, and groups.

Duration of Successful Milking during the 14-d Experimental Period

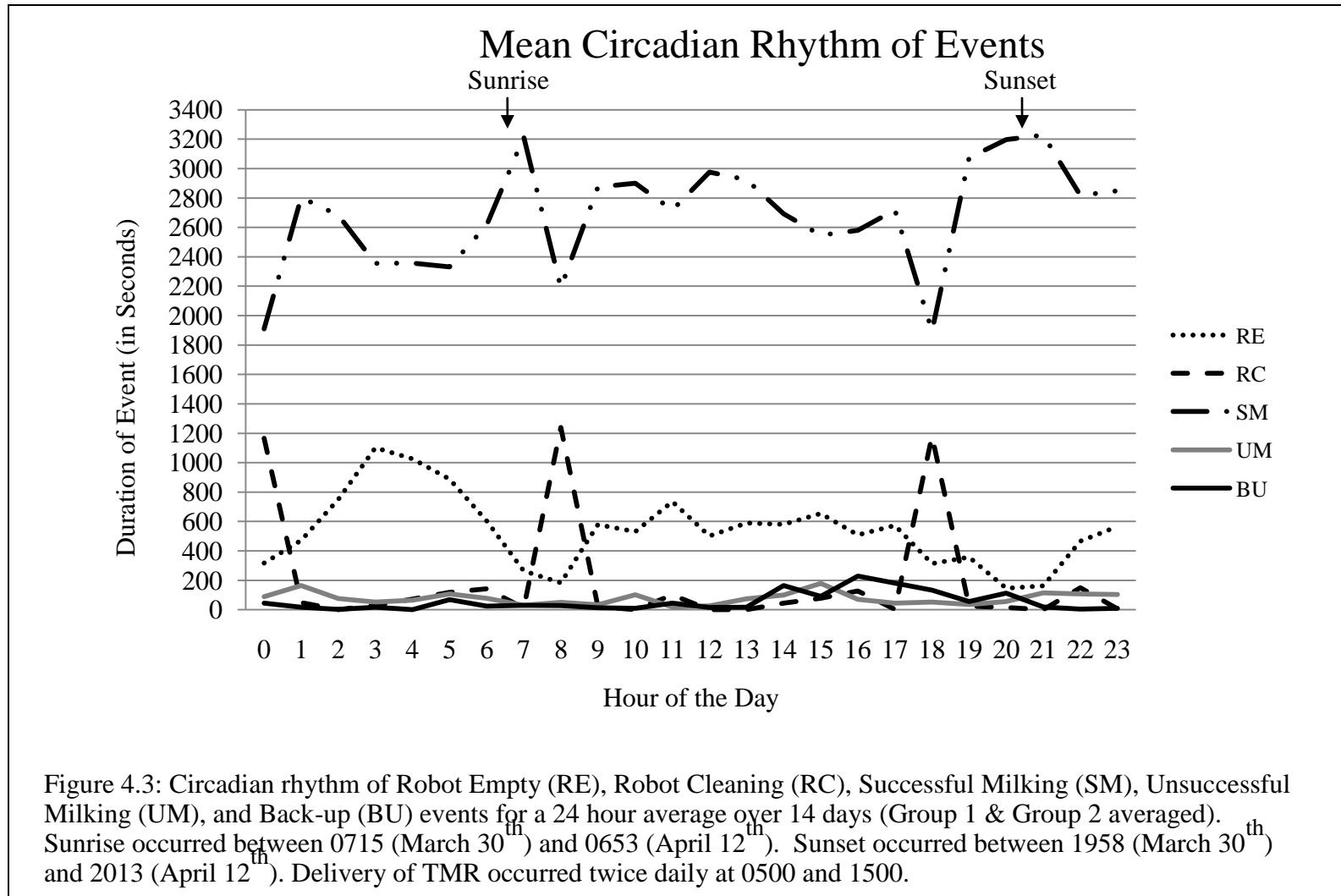|	Day						
Group	0	1	2	3	4	5	6
1	63009	64821	66107	63739	66542	65222	69853
2	63519	58611	58887	60535	60320	61766	64482
	Day						
Group	7	8	9	10	11	12	13
1	64094	68643	69476	68605	68610	70851	71987
2	57162	60878	60310	63239	62854	65276	64190

Group	14-day Average
1	67254
2	61573

Table 4.2: Total duration of successful milking events (in seconds) during each day of the experimental period. Back-up events varied greatly between days, and groups.

APPENDIX D

MEAN CIRCADIAN RHYTHM OF EVENTS

Figure 4.3: Circadian rhythm of Robot Empty (RE), Robot Cleaning (RC), Successful Milking (SM), Unsuccessful Milking (UM), and Back-up (BU) events for a 24 hour average over 14 days (Group 1 & Group 2 averaged). Sunrise occurred between 0715 (March 30th) and 0653 (April 12th). Sunset occurred between 1958 (March 30th) and 2013 (April 12th). Delivery of TMR occurred twice daily at 0500 and 1500.

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