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ABSTRACT

EFFECT OF FEEDING METHOD ON THE LEARNING OF FEEDING BEHAVIOUR IN GROWING DAIRY HEIFERS

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The objective of this dissertation was to determine the effects of different feed delivery methods on the behaviour, rumen health, and growth, as well as on the learning of behaviour of pre-pubertal dairy heifers. Thirty-two Holstein dairy heifers were fed, for 13 weeks, a ration of haylage and concentrate presented either as a total mixed ration (TMR) or top-dressed ration (TDR). All heifers were then switched to an unfamiliar TMR for 7 weeks. Heifers fed the TMR were able to more evenly distribute their feeding activity throughout the day and competed less for feed. These behaviours persisted across the ration change, suggesting that the animals had been conditioned to their feeding experience. Heifers fed the TMR also maintained more solid fecal consistency across the experiment, indicating that the effects on rumen health were persisting, as a direct result of the continuation and persistence of desirable feeding patterns and habits.
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CHAPTER 1: INTRODUCTION

The dairy industry has made major advances in the past few decades, particularly in the areas of nutrition, health and management (Eastridge, 2006). Recently, great strides have been made in recognizing the need for understanding the role that knowledge of dairy cattle behaviour can play in the improvement of health and management strategies (von Keyserlingk et al., 2009). In particular, we have seen a dramatic rise in the amount of scientific research relating behaviour to the health and production of dairy cattle (Weary et al., 2009). The suggestion has been made that feeding behaviour patterns, which relate to dairy cattle health and production, may be developed early on in life. This review will, therefore, explore how development and learning of feeding related behaviour occurs in cattle, how such behaviours relate to health and production of dairy cows, and identify areas of growing dairy heifer management where these behaviours may be influenced and developed.

1.1 Learning

Learning can be defined as a change in state due to experience (Chance, 1988). These changes in state have the potential to be manifested in behaviour (Shettleworth, 1998). Animals need to learn what foods are good to eat, and where and when to find it. The learning of feeding behaviour largely occurs due to the process of conditioning. Conditioning, also referred to as associative learning, is the formation of some sort of mental connection between representations of two stimuli (Shettleworth, 1998). There are different types of conditioning but the two most common forms are Pavlovian/classical and instrumental conditioning. In classical conditioning, the experimenter arranges a contingency between a neutral stimulus and a reinforcer; whereas in instrumental conditioning, the contingency exists between some aspect of
the animal’s behaviour and a reinforcer (Shettleworth, 1998). As such, animals become instrumentally conditioned to particular feeding habits and behaviours by associating these with a consequence (Kyriazakis et al., 1999). For example, when a food is consumed it may cause a particular post-ingestive action or consequence that will alter the internal state of the animal (reinforcer); the body then assesses what has changed through various receptors and actions alter accordingly, perhaps by changes in feed intake or preferences (Villalba and Provenza, 2009). The animal then develops a conditioned response, preference, aversion, etc. to the feeding event and continues to act accordingly.

For ruminants, learning what to eat and how best to accomplish the task of eating are important aspects of life while they are growing. Research has shown that experience with feeds and feeding strongly influences feeding behaviour in livestock and results in the development of nutritional wisdom, the recognition of properties relating to the nutritive value of a particular food and the ability of the animal to select a diet that will meet its nutrient requirements (Forbes, 2007; Villalba and Provenza, 2009). Nutritional wisdom encompasses both learned and innate food preferences and behaviours. For example, the requirement for certain nutrients (i.e. sodium) is innate in animals; animals deprived of sodium will rapidly consume salt water, when offered, in an effort to meet their needs. However, consumption of feeds high in energy, for example, may be high until the post-ingestive consequences of malaise are recognized by the animal, at which point the individual will likely decrease its consumption of that particular food (Dohme et al., 2008). Furthermore, learning of feeding patterns enables animals to lower the incidence of ingestion of toxic compounds due to negative consequences of such behaviour (Kyriazakis et al., 1998) and to increase their consumption of nutritive feedstuffs via positive post-ingestive consequences (Arsenos and Kyriazakis, 1999).
This learning in ruminants typically occurs through various means, including post-ingestive feedback related to choice of feed consumed, exposure to several different foods, and social interactions with others (including maternal influence).

Post-ingestive feedback can be defined as the ability of animals to discriminate among foods with their senses, and to sense the consequences of food selection through feedback mechanisms that are integrated within the central nervous system (Provenza, 1995; Arsenos and Kyriazakis, 1999). This feedback is evident in animals following ingestion of an excess of toxins or nutrients and also when animals experience a deficit in nutrients (Provenza, 1995). Many animals will consume nutritious plants with toxic properties, over consumption of which may cause toxicities, in limited quantities. It has been suggested that intake of such plants is limited due to a previous consumption experience in which malaise from over ingestion of toxins was experienced (Provenza et al., 1994a). Ruminants prefer high-energy foods such as grain, but have been shown to limit their intake of these foods and increase ingestion of other foods (i.e. long forages) when over ingestion of grain occurs (Britton and Stock, 1987; Phy and Provenza, 1994). These examples suggest that animals are learning what to eat, or what not to eat, through the development of conditioned preferences or aversions acquired due to post-ingestive consequences and feedback. Animals increase or decrease their ingestion of a particular food based on over or under ingestion of particular nutrients altering their internal state and causing discomfort (Kyriazakis et al., 1999). Thus, it appears that, when animals are given a choice of foods, they are able to regulate their feed intake and diet selection through post-ingestive consequences of previous selection, integrated with the ability to learn about the post-ingestive effects associated with a particular food.

What an animal remembers about past experiences with a food, then, can influence its future diet selection. For example, Burritt and Provenza (1997)
demonstrated that when sheep were offered a choice between a novel food, a familiar food, and a familiar, but aversive, food, the sheep tended to consume more of the familiar, but aversive, food than the novel food when offered in an unfamiliar environment. For dairy cattle, it could be hypothesized that when presented with an unfamiliar mixed ration containing at least one familiar component they may be more likely to try to select for and consume the familiar component. Furthermore, past experience with a food, particularly if that experience is gained early in life, can improve performance of animals later in life. When a low quality ammoniated straw was offered to calves early in life, it was found that these animals more readily consumed the straw when tested five to eight years later and that overall performance of the previously exposed animals was significantly improved over animals with no previous experience (Wiedmeier et al., 2002). For dairy cattle, this type of dietary learning may also be important. It could be hypothesized that dairy cattle that are familiar with a total mixed ration (TMR) from a young age, particularly a TMR containing many similar components to a lactating ration, may be more likely to consume any TMR more readily than if they had never seen a ration presented in this visual form or utilizing a similar texture. Experience with a TMR from a young age, then, may help to ensure sufficient DMI later in life.

Finally, the social environment within which an animal exists can influence their diet selection as well as aid in social learning processes. There is a variety of research, involving various species, in which a maternal influence on diet selection has been exhibited (Thorhallsdottir et al., 1987; Mirza and Provenza, 1990; Provenza et al., 1993). Mirza and Provenza (1994) found that lambs whose mothers had been conditioned to avoid a plant tended to consume less of that plant than lambs with no previous experience with the plant. As such, the lambs' diet selection was indirectly mediated by
their mother's preference or avoidance behaviour. Nutritional wisdom is not, however, strictly passed down through maternal means. Heifers trained to avoid consumption of larkspur by conditioning with lithium chloride (a substance evoking mild toxicosis symptoms) lost this aversion more quickly when kept with unconditioned heifers (Ralphs and Olsen, 1990). Chapple et al. (1987) found that sheep unfamiliar with wheat consumed wheat much more readily when exposed to the feedstuff with experienced sheep. As such, social situations may facilitate the learning of behaviour. It could be hypothesized, therefore, that dairy cattle that develop undesirable or detrimental feeding behaviours may, in turn, influence their peers to develop these feeding patterns. Conversely, based on this previous research, animals that have learned proper feeding patterns may have a positive influence on the development of good feeding behaviour in their peers, particularly younger animals.

Although researchers have shown several areas where learning of feeding behaviour occurs in ruminant animals, it is important to note that this work has been conducted with extensively-grazed animals (particularly sheep and beef cattle) as opposed to intensively-housed animals (such as dairy cattle). Conditions for animals raised in an intensive environment, are well controlled and managed. It is, therefore, unclear how learning may differ for animals in this situation. Furthermore, it is important to understand how the development of feeding behaviours, patterns, and habits occur, as it is possible that many of these may have a major impact on the production potential, health and welfare of the adult cow.

1.2 Feeding Behaviour in Adult Cattle

Dairy cattle are grazers and, as such, under natural conditions would engage in foraging behaviour for 4-9 hours per day (Hafez and Bouissou, 1975). Modern, high-
production dairy cows typically consume their daily DMI in 3-5 hours per day, spread between 6-10 meals (Tolkamp et al., 2000; DeVries et al., 2003). These meals may be spread throughout the day, with the largest ones occurring after the delivery of fresh feed (DeVries et al., 2003).

It has been suggested that management practices that cause adult dairy cattle to eat fewer and larger meals more quickly may be associated with an increased incidence of sub-acute ruminal acidosis (SARA; Krause and Oetzel, 2006). The reason for this risk is that ruminal pH declines following meals and the rate of pH decline increases as meal size increases and as dietary effective fibre concentration decreases (Allen, 1997). During periods of peak feeding activity, such as after delivery of fresh feed (DeVries and von Keyserlingk, 2005), there is an increase in the number of animals present at the feed bunk and, as such, an increased amount of competition during those time periods (Olofsson, 1999). This competition can lead to an increase in time spent standing, increasing the risk of development of hoof disorders or lameness (Proudfoot et al., 2009). Furthermore, competitive behaviours lead to a rapid intake of the diet (or slug feeding; Proudfoot et al., 2009). Rapid consumption of feed may result in decreased salivary secretion (Beauchemin et al., 2008), thus decreasing the buffering capacity of the rumen. This may result in large postprandial drops in rumen pH, increasing the risk for SARA or problems with rumen fermentation (Stone, 2004). Recent research has suggested reducing stocking density and providing physical partitions between adjacent cows at the feed bunk will reduce competitive behaviour at the feed bunk (DeVries et al., 2004; DeVries and von Keyserlingk, 2006; Huzzey et al., 2006). Despite these management strategies, competitive behaviour continues to occur on dairy farms, necessitating further research on methods of elimination or minimization of this behaviour.
Total mixed ration feeding systems are designed to provide a balanced intake of nutrients to all animals without allowing for individual feed preferences or sorting (Coppock, 1977). Despite this goal, dairy cattle are still able to selectively consume for certain feed components. This selective consumption, or sorting, is typically manifested in cows discriminating against the longer forage particles and selectively consuming the smaller concentrate components of a mixed diet (Leonardi and Armentano, 2003; DeVries et al., 2007). As a result, this feeding related behaviour has consequences on health and productivity. The sorting of a TMR by dairy cows can result in the ration actually consumed by cows being higher in fermentable carbohydrates than intended and lower in effective fibre, thereby increasing the risk of SARA (DeVries et al., 2008). For group-housed cattle the problem with sorting behaviour is two-fold. Firstly, those cattle that dominate the feed bunk after the delivery of fresh feed (DeVries et al., 2004) may engage in much sorting, particularly for short concentrate particles, and be at risk for SARA (Hosseinkhani et al., 2008). Alternatively, those subordinate cattle with poor bunk access after feed delivery, may be forced to wait to feed (DeVries et al., 2004) and end up consuming a ration that is sorted and of reduced nutritive value (Leonardi and Armentano, 2003; DeVries et al., 2005). As such, these cows may not be able to maintain adequate nutrient intake to meet their energy and essential nutrient requirements (Krause and Oetzel, 2006). There has been much research in recent years attempting to minimize or eliminate sorting behaviour. Much progress on this front has been made, in particular through altering diet composition (Kononoff et al., 2003; Leonardi and Armentano, 2003; DeVries et al., 2007) and feeding management (DeVries et al., 2005; Leonardi et al., 2005). Despite these discoveries, the occurrence of this behaviour remains high. This would suggest that further work is needed to try to further minimize or eliminate this behaviour, possibly by preventing its development in dairy cattle.
Detrimental feeding behaviours, such as those reviewed, may have a serious impact on the production potential, and possibly also the growth and development, of the growing dairy heifer. Although it is known that some of these feeding behaviours exist in young dairy animals, previous research has not been focused on the development of these behaviours. Furthermore, it is not clear whether these behaviours develop early in life and/or if they are affected by various feed management systems. It is important to understand the development of these feeding patterns and behaviours so that we may develop management strategies to prevent problems from occurring later in life.

1.3 Feeding Behaviour in Young Cattle

Replacement dairy heifers represent the future potential of the dairy industry. Despite this, they are largely overlooked on dairy farms. Heifer rearing provides very little benefit to producers until these animals reach lactating age and begin to produce calves and milk for the farm (Hutjens, 2004). The costs associated with replacement dairy heifer rearing are second only to the feed costs of lactating cows, representing 15 to 20% of total farm expenses (Heinrichs, 1993). Improper management from an early age may contribute to problems with growth and production throughout the life of the animal, increasing the overall costs to the producer (Quigley, 1997). As feed costs represent over 50% of overall costs associated with raising heifer replacements (Cady and Smith, 1996), improvements in feeding management will greatly help in minimizing the rearing costs of replacement heifers.

It is now a common practice to feed a TMR to all cattle on-farm over the age of 6 mos (DeVries and von Keyserlingk, 2009a). However, younger dairy cattle are typically provided with a ration composed of a grain concentrate and some form of roughage (Heinrichs and Swartz, 1990; Murphy, 2004). This ration is then presented as either
separate components or as a top dressed ration (concentrate spread over roughage). Although this is typical practice in the industry at this time, it has been suggested that feeding a TMR to all cattle on-farm would provide a more balanced nutrient intake, while helping to prevent individual preferences for dietary components (development of sorting behaviour) and other adverse feeding behaviours from developing (Borland and Kesler, 1979).

DeVries and von Keyserlingk (2009a) recently demonstrated that, when fed ration components separately or when provided with a grain concentrate top dressed on hay, dairy heifers will rapidly consume the grain portion of their ration in a few, large meals prior to consuming the hay portion of the ration. This type of feeding pattern (rapid consumption of large meals) is known as ‘slug feeding’. There has been speculation that the ‘slug feeding’ exhibited by heifers when fed a top-dressed or a component ration may cause significant post-prandial drops in rumen pH, possibly resulting in an increased incidence of SARA (Quigley, 1992; DeVries and von Keyserlingk, 2009a). It is important, therefore, to consider the effects of feeding method and feeding patterns on rumen health. However, rumen pH or any indicators of rumen health were not addressed in previous research. Furthermore, knowledge of the development and persistence of these feeding patterns would greatly aid in the creation of feeding management strategies to minimize or eliminate the development of these detrimental behaviours.

Another adverse feeding related behaviour is competition at the feed bunk. Previous research with cattle has shown greater competition for the concentrate component of the ration when fed separately from forage (Herlin and Frank, 2007; Gonzalez et al., 2008). Given the previously discussed consumption patterns seen in heifers (DeVries and von Keyserlingk, 2009a), it is possible that certain heifers may dominate the feed bunk when fed in a group situation. It is likely, then, that dominant
animals would consume more concentrate than intended, particularly during peak feeding times. However, researchers have not yet considered the long-term effects of feed delivery methods on the behaviour and growth of the heifers, or the effect on group-fed heifers.

As previously discussed, one undesirable feeding behaviour is that of sorting the ration. Much work has been done with adult dairy cattle on this issue, but there have been few studies looking at sorting behaviour in dairy heifers (Hoffman et al., 2006; Greter et al., 2008; DeVries and von Keyserlingk, 2009a,b). Recent research has shown that when prepubertal dairy heifers are fed a TMR, they will sort for the short particles (composed mainly of the concentrate portion of the ration) and against the longer forage particles (Greter et al., 2008; DeVries and von Keyserlingk, 2009a,b). It is not clear, however, when and how this behaviour developed in these animals. DeVries and von Keyserlingk (2009a) found that sorting for short particles occurred to a greater extent with animals fed a top-dressed ration as opposed to heifers fed a TMR, providing evidence that the concentrate component (which largely made up the short particles) was more easily accessible to those heifers. The repeated feeding pattern of ingestion of the readily available concentrate component of the diet by heifers fed the top-dressed ration may have conditioned the heifers to this sorting behaviour. As such, this detrimental feeding behaviour may persist as the animals are moved to a new ration or to a TMR, resulting in associated problems with competition, digestive health and poor nutrition. It is important, therefore, to establish when this behaviour is developing and what factors influence the development of the behaviour.
1.4 Objective and Hypothesis

It is clear, then, that there are several undesirable and detrimental feeding related behaviours that exist in adult dairy cattle, which have significant effects on cow production, health, and welfare. Furthermore, some of the behaviours have been observed in young dairy heifers. It is unknown, however, when these behaviours develop and what factors contribute to this learning process.

The objective of this dissertation was, therefore, to determine the effects of exposure to different feed delivery methods on the behaviour, rumen health, and growth, as well as on the learning of feeding and competitive behaviour of pre-pubertal dairy heifers. Our hypotheses were that heifers fed a TMR would pattern their feeding behaviour more evenly throughout the day, engage in less sorting behaviour, compete less for their feed, exhibit good rumen health as seen by solid fecal consistency, and gain weight more rapidly than top-dressed fed heifers. We also hypothesized that longer-term feeding a TMR would result in persistence of these feeding behaviour patterns. These hypotheses were addressed in a two-part experiment that was conducted from June to November 2008.
CHAPTER 2: EFFECT OF FEED DELIVERY METHOD ON THE BEHAVIOUR AND GROWTH OF DAIRY HEIFERS

2.1 Introduction

Raising replacement dairy heifers is one of the highest input production costs and has little benefit to producers until heifers reach lactating age (Hutjens, 2004). Improper management from an early age may contribute to problems with growth and production throughout the life of the animal, further increasing overall costs to the producer (Quigley, 1997).

Much time and effort has been spent on developing efficient feeding management systems for adult dairy cattle. Total mixed ration feeding systems are designed to provide a balanced intake of nutrients to all animals without allowing for individual preferences or sorting (Coppock, 1977). It is now a common practice to feed a TMR to all cattle on-farm over the age of 6 mos. (DeVries and von Keyserlingk, 2009a). Younger dairy cattle are often provided with a diet composed of a grain concentrate and some form of roughage (Murphy, 2004), presented as either separate components or as a top dressed ration (concentrate spread over roughage). It has been suggested that feeding a TMR to all cattle on-farm would provide a balanced nutrient intake, while helping to prevent individual preferences for dietary components and other adverse feeding behaviours from developing (Borland and Kesler, 1979).

DeVries and von Keyserlingk (2009a) demonstrated that growing dairy heifers, when given a choice of ration components, or when provided grain concentrate top dressed on hay, rapidly consume the grain concentrate portion of their ration in very few, large meals prior to consuming the hay portion of their ration. These researchers found that the provision of a TMR increased the distribution of DMI over the course of the day.
and reduced the amount of sorting against forage and for concentrate. DeVries and von Keyserlingk (2009a) concluded that the provision of a TMR to growing dairy heifers may promote a more balanced intake of nutrients across the day. These researchers did not consider the longer-term effects of these feed delivery methods on the behaviour and growth of the heifers, or the effect on group-fed heifers.

Greater competition for the concentrate component of a ration, particularly when it is fed separately from forage, has been previously demonstrated in cattle (Herlin and Frank, 2007; Gonzalez et al., 2008). Given the consumption patterns of dairy heifers fed a component or top-dressed ration, certain heifers may dominate the feed bunk in a group feeding situation, particularly during peak feeding times, and consume more concentrate than intended. DeVries and von Keyserlingk (2009a) also speculated that the rapidly consumed, large concentrate meal feeding, or ‘slug feeding’, exhibited by heifers when fed a top-dressed or a component ration may cause significant post-prandial drops in rumen pH. Slug feeding is widely acknowledged as a negative feeding behaviour pattern in adult dairy cows, which may result in sub-acute ruminal acidosis (SARA; Stone, 2004).

The objective of this study was to determine the effects of exposure to different feed delivery methods on growth, as well as on the feeding behaviour and feeding competition of pre-pubertal dairy heifers. Our hypothesis was that heifers fed a TMR would pattern their feeding behaviour more evenly throughout the day, engage in less sorting behaviour, compete less for their feed, exhibit good rumen health as seen by solid fecal consistency, and gain weight more rapidly than top-dressed fed heifers.
2.2 Materials and Methods

2.2.1 Animals and Housing

Thirty-two Holstein dairy heifers were used in this study and were acquired, on loan, from a local commercial dairy operation. Heifers were given a broad-spectrum antibiotic (Draxxin, tulathromycin, Pfizer Animal Health, Kirkland, Quebec, Canada) upon arrival to prevent impending respiratory disease due to transport and mixing stresses (Stanton et al., 2010). Heifers were given a 12-d adaptation period following arrival at the research facilities. The heifers were 146.2 ± 21.9 (mean ± SD) d of age, weighed 165.2 ± 25.1 kg, and measured 102.8 ± 3.8 cm high at the withers at the beginning of the experiment. Heifers weighed 278.4 ± 31.3 kg and measured 117.5 ± 3.2 cm high at the withers at the end of the experiment. Heifers were housed in groups of 4 in 8 pens in the heifer research barn at the University of Guelph, Kemptville Campus (Kemptville, ON, Canada) and were managed according to the guidelines set by the Canadian Council on Animal Care (1993). Use of heifers was approved by the University of Guelph’s Animal Care Committee (AUP#08R011). The experiment was conducted between June and September 2008. The pens, located in a naturally-ventilated cold barn, consisted of an indoor sawdust-bedded pack area (3.6 x 10.9 m; width x depth) and an outdoor concrete run (3.6 x 16.4 m). Bedding material was replenished as needed. Feed bunks were located along the front of each pack area within each pen and measured 1.35 m in length, allowing for 0.34 m of bunk space per heifer. The heifers were provided ad libitum access to feed. Orts were cleaned out of the feed bunks at 1030 h each day, with new feed delivered once daily at 1200 h. Water was available ad libitum through a water bowl in each pen. Heifers were also given ad libitum access to trace mineral salt blocks (Windsor TM Stock Salt, The Canadian Salt Company Limited, Pointe-Claire, Quebec).
2.2.2 Experimental Design and Diets

The number of replicates required per treatment was determined through power analysis (Morris, 1999) for the primary response variables, including feeding and sorting behaviour, DMI, and ADG. Estimates of variation for these variables were based on previously reported values (Kertz and Chester-Jones, 2004; DeVries and von Keyserlingk, 2009a). Heifers were divided into 8 groups of 4 that were balanced for age and weight. All heifers were fed a diet consisting of 65% grass/alfalfa haylage and 35% commercial heifer grower textured concentrate (Table 2.1). This ration was formulated according to the NRC (2001) nutrient recommendations for a non-bred Holstein heifer growing at 1.0 kg/d. During the adaptation period, dietary components were fed separately to prevent sorting behaviour. Following the adaptation period, groups were randomly assigned to 1 of 2 treatment diets: 1) total mixed ration (TMR) and 2) top-dressed ration (TDR), in a completely randomized design. Heifers remained on their respective treatments for 13 wks.

Haylage was delivered each day via a mixer wagon. The necessary amount of haylage and concentrate were manually weighed out for each pen. For the TMR treatment, the haylage and concentrate were thoroughly mixed on the cement floor in front of each feed bunk for 5 min using a pitchfork. After mixing was complete, feed was placed into the feed bunk. For the TDR, haylage was placed into the feed bunk, followed by spreading the concentrate component on top of the forage. The total amount of feed offered was adjusted daily to ensure 5-10% orts per pen. The actual orts averaged 4.5 ± 4.1% (mean ± SD) DM of offered feed over the course of the experiment.

2.2.3 Experimental Measurements

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Group intakes were recorded daily throughout the study by weighing the amount of feed offered and amount of feed refused. This data was used to calculate daily DMI (kg/d) on a pen basis. Heifers were weighed and measured on the same weekday at the same time every 2 wks to measure weight gain and growth rate (ADG). Additionally, heifers were fecal scored for consistency of feces twice weekly using a scale from 1 (liquid) to 4 (solid; Ireland-Perry and Stallings, 1993).

Feeding and competitive behaviour were monitored, using time-lapse video equipment, continuously for all 7 d of each recording week: weeks 1, 5, 9, and 13 of the study. Heifers were recorded using 1 video camera (Panasonic WV-BP330; Osaka, Japan) per 2 pens, a time-lapse video cassette recorder (Panasonic AG-6740), and a video multiplexer (Panasonic WJ-FS 616). Video cameras were located 3.2 m above the feed bunk, between two pens. Red lights (100 W), hung adjacent to the cameras, were used to facilitate recording at night. Individual heifers were identified within each pen with unique neck collars.

The amount of time spent feeding during all 7 d of each recording week was scored for individual heifers from video using instantaneous scan sampling every 10 min. For each scan, a heifer was recorded as feeding when its head was completely past the feed rail and over the feed. These scans were then used to calculate the total time spent feeding by multiplying the number of scans by 10 (Endres et al., 2005). Time spent feeding was then calculated for each heifer for each day of the recording weeks (min/d). Additionally, to detect changes in the diurnal pattern of feed bunk attendance, these scans were used to calculate the percentage of heifers feeding over the course of each 24-h period. Based on these diurnal patterns, we also calculated feeding time for each heifer during the 2-h period (period of peak feeding activity) following the delivery of feed, when feeding activity was greatest.
Feeding competition, recorded as displacements from the feed bunk while feeding, was measured on d 2, 4, and 6 of each recording week. A displacement was noted when a butt or a push from the actor (instigator) resulted in the complete withdrawal of the reactor’s head from beneath the feed rail (DeVries et al., 2004). These observations were used to calculate, according to DeVries et al. (2004), an agonistic interaction success rate (AISR) for each individual heifer. A successful interaction occurs when one heifer (dominant) successfully manages to completely displace another (subdominant) from the feed bunk. The heifers were classed as being either above or below the focal animal in rank. The AISR was calculated as follows: number of individuals subdominant to focal heifer / number of individuals dominant to focal heifer + number of individuals subdominant to focal heifer x 100%.

During each of the recording weeks, when feeding behaviour was monitored, standing and lying behaviour were also measured. Daily lying times of individual heifers were obtained via electronic data loggers (HOBO Pendant G Data Logger, Onset Computer Corporation, Pocasset, MA). These small devices were attached to the hind leg of each heifer using veterinary bandaging (Vetrap Bandaging Tape, 3M, St. Paul, MN) and measured the orientation of the leg at 1-minute intervals. These data were summarized to calculate the average lying time and the average number of lying bouts for each heifer.

2.2.4 Feed Sampling and Analysis

A representative sample of the ration was collected, for particle size separation, at the time of feed delivery each day during the recording weeks. Orts samples, for particle size separation, were taken from each feed bunk at the end of each recording day when the feed bunks were cleaned out. Samples of the TMR and orts from each pen
were taken twice weekly throughout the experiment for DM and chemical analysis. Samples of the dietary components were also taken once a week for DM and chemical analysis. Duplicate samples of forage components were taken during the recording weeks for particle size separation. All samples were immediately frozen at -20°C until they were further analyzed.

Samples for particle size separation were separated using the 3-screen (19, 8, 1.18 mm) Penn State Particle Separator (PSPS; Kononoff et al., 2003). Samples were separated into 4 fractions: long (>19 mm), medium (<19, >8 mm), short (<8, >1.18 mm), and fine (<1.18 mm) particles. After separation, the DM of each separated fraction was determined by oven drying at 55 °C for 48 h.

Dry matter content of samples taken for chemical analysis was determined by drying samples in a forced-air oven at 55 °C for 48 h. These samples, plus the dried TMR particle fractions, were then ground to pass through a 1-mm screen (Wiley Mill, Arthur H. Thomas Co., Philadelphia, PA). The ground samples were then sent to Cumberland Valley Analytical Services Inc. (Maugansville, MD, USA) for analysis of DM (135°C; AOAC, 2000: method 930.15), ash (535°C; AOAC, 2000: method 942.05), ADF (AOAC, 2000: method 973.18), NDF with heat-stable α-amylase and sodium sulfite (Van Soest et al., 1991), CP (N x 6.25) (AOAC 2000: method 990.03; Leco FP-528 Nitrogen Analyzer, Leco, St. Joseph, MI) and starch (Holm et al., 1986).

2.2.5 Calculations and Statistical Analysis

Sorting was calculated as the actual DMI of each fraction of PSPS expressed as a percentage of the predicted DMI of that fraction (Leonardi and Armentano, 2003). The actual intake of each individual fraction was calculated as the difference between the DM amount of each fraction in the offered feed and that in the refused feed. The predicted
intake for each individual fraction was calculated as the product of the DMI of the total diet multiplied by the DM percentage of that fraction in the offered diet. Values equal to 100% indicate no sorting, <100% indicate selective refusals (sorting against), and >100% indicate preferential consumption (sorting for).

For analyses of treatment effects, the pen was considered as the experimental unit. The DMI and sorting behaviour data were calculated on a pen basis and averaged by week for the entire experiment. Growth (ADG) was averaged on a pen basis by two-week period for the entire experiment. Pen variance in ADG (ADGv) was calculated by averaging, per pen, the absolute difference between individual heifer ADG and pen mean ADG. Feeding, competitive, and lying behaviour data were averaged across heifers within each pen and days to create one observation per recording week per pen. Data for feed bunk attendance (% of heifers feeding) were summarized by hour for each pen on each treatment.

Preliminary screening of the data revealed that all dependent variables were normally distributed. To test whether sorting of the experimental diets occurred, data for each PSSP fraction was tested for a difference from 100 using t-tests within the MIXED procedure of SAS (2003). To test for the effect of treatment, all data were analyzed using the MIXED procedure of SAS (2003) treating week as a repeated measure. Appendix 1 provides examples of the SAS codes used for these analyses. The model included the fixed effects of treatment and week, and the random effect of pen within treatment. The variance-covariance error structure was first-order autoregressive, variance components, or first-order heterogeneous autoregressive, depending upon best fit according to Schwarz’s Bayesian information criterion. To test for effect of treatment on feed bunk attendance patterns, these data were analyzed using the MIXED procedure of SAS (2003) treating hour as a repeated measure. The model included the
fixed effects of treatment and hour and the random effect of pen within treatment. The variance-covariance error structure was first-order autoregressive, according to best fit with Schwarz’s Bayesian information criterion. All values reported are least squares means.

To test the hypothesis that socially subordinate heifers would be most affected in their response to the treatments, measures of growth, feeding time, and fecal score were regressed within treatment on the heifer’s AISR using the regression procedure of SAS (2003). Only those statistically significant models are shown. For all analyses, significance was declared at \( P \leq 0.05 \), and a trend was reported if \( 0.05 < P \leq 0.10 \).

2.3 Results

Analysis of the diurnal feed bunk attendance of heifers showed a treatment by hour interaction (SE = 0.3, \( P < 0.001 \); Figure 2.1), with an increased percentage of heifers fed the TDR present at the feed bunk during the 2 h after feed delivery (period of peak feeding activity). Although there was no difference in daily feeding time between treatments, heifers fed a TDR spent more time at the feed bunk during the period of peak feeding activity (Table 2.2). The AISR was negatively correlated with feeding time (\( y = -0.4x + 217.3; R^2 = 0.27, P = 0.04 \)) and tended to be negatively correlated with peak feeding time (\( y = -0.1x + 36.2; R^2 = 0.23, P = 0.06 \)) for heifers fed the TMR, whereas there was no relationship between AISR and feeding time \( (P = 0.6) \) or peak feeding time \( (P = 0.9) \) for heifers fed the TDR.

The number of displacements, as measured by the number of times a heifer was physically displaced from the feed bunk, was higher for heifers fed the TDR than for those fed the TMR across the day, especially during periods of peak feeding activity.
(Table 2.2). Daily lying time and the number of lying bouts of heifers was also unaffected by treatment (Table 2.2).

There was a treatment by week interaction for the sorting of long ($P = 0.04$; Figure 2.2), medium ($P = 0.02$), and short ($P = 0.03$) particles. Heifers sorted against long particles (>19 mm) to a greater extent when fed the TDR compared to when fed the TMR (Table 2.3). When provided the TMR, heifers did not sort for or against medium particles, whereas on the TDR, heifers sorted against medium particles (Table 2.3). Heifers consumed more of the short particles when fed the TDR as compared to when fed the TMR (Table 2.3). Heifers on the TMR sorted against fine particles, whereas heifers on the TDR sorted for fine particles (Table 2.3).

Heifers fed the TDR had lower fecal scores than those fed the TMR (Table 2.2), with lower fecal scores indicating loose stool. However, fecal scores of heifers fed the TMR tended to be positively correlated with AISR ($y = 0.01x + 3.2; R^2 = 0.24$, $P = 0.06$), whereas there was no relationship between fecal score and AISR for heifers on the TDR ($P = 0.4$). Even though DMI did not differ between treatments, heifers fed the TDR consumed less NDF than heifers fed the TMR (Table 2.2). Average daily gain and ADGv were similar between treatments (Table 2.2). However, the ADG of heifers on the TDR was positively correlated with AISR ($y = 0.002x + 1.2; R^2 = 0.33$, $P = 0.02$), whereas there was no relationship between ADG and AISR in heifers fed the TMR ($P = 0.2$).

2.4 Discussion

There was a peak in feeding activity immediately following feed delivery by heifers on both treatments. This feeding pattern is typical for both young and adult dairy cattle (DeVries et al. 2003; DeVries and von Keyserlingk, 2005, 2009a). Daily feeding time was similar between treatments, as was daily lying time. In support of our
hypothesis, we found that heifers fed the TDR spent over 60% more time at the feed bunk during the 2h period of peak feeding activity following feed delivery. This translated into there being 15% more heifers, on average, at the feed bunk during this time period. DeVries and von Keyserlingk (2009a) recently found that heifers fed a TDR consumed greater DM during the period of peak feeding activity following feed delivery than heifers fed a TMR. Additionally, this intake pattern was found to be similar to that of the choice-fed heifers, with all concentrate consumed in 2 meals or less during this time period (DeVries and von Keyserlingk, 2009a). Based on these results, those researchers speculated that heifers fed a TDR also consumed the concentrate component of their diet, in a slug feeding pattern, prior to consuming their forage. It is possible, then, that heifers fed the TDR in the present experiment were also consuming more during peak feeding periods than heifers fed a TMR, likely due to the consumption of the concentrate component of the ration apart from the forage. Data from Quigley et al. (1992) also supports the hypothesis that these heifers may have been slug feeding during peak feeding time as calves in that study exhibited similar behaviour when fed calf starter and hay separately. This slug feeding pattern is not surprising since the concentrate component of the ration was much more easily accessible in the TDR than in the TMR.

Slug feeding is often described as a negative feeding behaviour pattern in adult dairy cows, which may result in sub-acute ruminal acidosis (SARA; Stone, 2004). Additionally, Quigley et al. (1992) found that there were postprandial drops in rumen pH in the calves following the slug feeding incidents. It could be hypothesized that such feeding patterns are learned early in life, as a result of factors such as feed delivery method, and may persist as the animal matures. Further research to address this hypothesis is encouraged.
The negative correlation between AISR and feeding time and tendency for a negative correlation between AISR and peak feeding time for heifers fed the TMR indicates that dominant heifers spent less time feeding during peak feeding activity and throughout the day than subordinate heifers. Alternatively, access to feed in heifers fed the TDR was unaffected by dominance status. This suggests that there may have been a strong desire to consume the concentrate component of the diet, forcing the subordinate heifers to try to out-compete the dominant heifers to consume the concentrate. It is not surprising, therefore, that heifers fed the TDR exhibited over twice the number of displacements at the feed bunk per day compared to those fed the TMR, further supporting our hypothesis. This translated into heifers fed the TDR being displaced over three times more than heifers fed the TMR during the period of peak feeding activity. In fact, heifers fed the TDR performed a greater percentage (37%) of their daily displacements during this time period than heifers fed the TMR (22%). This finding provides further evidence that access to the concentrate component of the ration was increasing the competition level in the pen. Greater competition for concentrate, when it is fed separately from forage, has been previously demonstrated in cattle (Herlin and Frank, 2007; Gonzalez et al., 2008). Further, feeding competition has been shown to cause heifers to consume fewer meals per day, which are larger and longer in duration (DeVries and von Keyserlingk, 2009b). Although meal data was not measured in this study, it could be assumed that that heifers fed the TDR were consuming feed in a similar intake pattern to that of the competitively-fed heifers in the DeVries and von Keyserlingk (2009b) study. As a result, the heifers fed the TDR would be consuming large grain meals immediately following feed delivery and fewer overall meals throughout the day. The increased competition observed in the heifers fed the TDR could have negative long-lasting impact if this behaviour persists. Proudfoot et al (2009) recently demonstrated that feeding competition in transition dairy cows negatively
impacts feeding and standing behaviour, resulting in lower DMI and potentially increases the risk of lameness or other disease. Further research is, therefore, needed to determine the long-term persistence of such competitive behaviour on production and performance of the heifers as they reach breeding and lactating age.

The lack of difference in DMI between treatments is consistent with the results of DeVries and von Keyserlingk (2009a) from their study considering short-term effects of various feed delivery methods. It is important to note that, although there was no difference in DMI, there were differences in diet selection between treatments, suggesting that heifers were consuming different proportions of nutrients. Heifers fed the TDR sorted against long forage particles to a greater extent than heifers fed the TMR for the much of the length of the experiment. As a result, the amount of NDF consumed was less for those heifers fed the TDR. Overall, heifers fed the TDR consumed the short ration particles to a greater extent than those fed the TMR. Given that the short fraction of the ration consisted mainly of the concentrate component, this provides further evidence that top dressing increased the accessibility of that fraction of the ration. The slug-feeding pattern seen following feed delivery as well as the greater selection against the long forage particles and increased consumption of the concentrate portion of the ration by the heifers fed the TDR may result in problems with rumen fermentation, as such feeding patterns have been related to reduced rumen pH in adult dairy cattle (DeVries et al., 2008). Although heifers fed the TDR sorted for fine particles, and heifers fed the TMR sorted against fine particles, it is unlikely that there was any biological significance of this sorting, since fine particles represented only ~ 5% of the ration.

Contrary to our hypothesis, the difference in sorting between treatments disappeared by the end of the experiment. The treatment by week interaction for sorting of long, medium, and short particles indicated greater treatment differences seen during
the first week of the experiment. Of particular note was a 6% difference (91.4 vs. 96.8%) between treatments in sorting of long particles during the first week of treatment (Figure 2.2). These sorting differences between treatments decreased over time as the heifers became accustomed to the feed delivery methods. By the final recording week, there was very little sorting of long particles (98.3 vs. 99.1%) observed on either treatment. This acclimation is of particular interest, as it suggests that the heifers may have adjusted their sorting patterns over time, while remaining consistent in their feeding patterns. This would suggest that feeding patterns developed early on are more likely to be retained, while sorting patterns are more flexible over time. Future research in this area should focus on determining what factors may influence this flexibility in sorting behaviour.

As heifers fed the TDR competed more for feed, spent more time feeding immediately following feed delivery, selected against longer forage particles and consumed shorter concentrate particles to a greater extent, and had lower NDF intake, it is not surprising that these heifers also had looser stool, as indicated by lower fecal scores throughout the experiment, compared to heifers fed the TMR. Researchers have shown that cattle rapidly consuming concentrate are likely to experience more SARA due to postprandial drops in rumen pH (Østergaard and Grohn, 2000; Gonzalez et al., 2008). It is possible that the young dairy heifers in the present study experienced similar effects on rumen pH. Heifers fed the TDR may have experienced an increase in rumen osmolality following the rapid consumption of starch and greater refusal of effective fiber and, thus, increased water movement into the rumen, resulting in diarrhea (lower fecal scores; Kleen et al., 2003). Previous research has shown that loose stool can be used as an indicator of problems with rumen/digestive health and may be used as an indicator of reduced pH (Nocek, 1997; Krause and Oetzel, 2006). Heifers consuming the TMR,
conversely, consumed a more balanced diet overall, which would likely contribute to improved digestive health (Coppock, 1977; Borland and Kesler, 1976) and welfare. The positive correlation between AISR and fecal score for the heifers fed a TMR indicates that more dominant heifers exhibited more solid feces and, thus, may have had better rumen health than subordinate heifers. Furthermore, the lack of relationship between fecal score and AISR for heifers fed the TDR, suggests that all heifers were affected by this feed delivery method, regardless of social status. This may be due to the intake of an unbalanced diet by all heifers within these groups. Unfortunately, the composition of the diet consumed throughout the day was not measured and, therefore, we cannot be certain of what these heifers were consuming following feed delivery. Moreover, it was not possible to measure rumen pH in this study, which could have provided more concrete evidence of SARA. Thus, further research is needed to determine the effect of feed delivery method on rumen pH, and any possible occurrence of SARA, as well as the actual composition of the ration consumed throughout the day.

Despite the ration being formulated according to NRC (2001) recommendations for a non-pregnant replacement Holstein heifer, heifers in this study consumed more feed than predicted (7.3 vs. 6.2 kg/d), resulting in higher energy intake than predicted (18.8 vs. 14.5 Mcal/d). As such, higher ADG than predicted was maintained throughout the trial (1.3 vs. 1.0 kg/d). It was recently summarized by Hoffman et al. (2008) that heifers typically consume 1.0% of their BW in NDF. According to this formula, heifers in the present study should have been consuming, on average, 2.2 kg/d of NDF. The heifers in our study consumed NDF in excess of this amount (1.16% of their BW in NDF), thus contributing to the higher than predicted ADG. Contrary to our hypothesis, there was no difference in ADG or ADGv between treatments. There has been recent evidence suggesting that lactating dairy cattle affected with SARA are able to maintain
similar milk production as unaffected cows (O’Grady et al., 2008). As such, these animals seem able to acclimate to metabolic or production challenges and balance resources accordingly. It is possible, therefore, that heifers fed the TDR were able to react in a similar manner and were able to gain, on average, as efficiently as heifers fed the TMR. There was, however, a positive correlation between AISR and ADG in heifers fed the TDR, suggesting that socially dominant heifers gained more than submissive heifers. This is possibly due to higher intake of the concentrate component of the diet, as well as fewer displacements from the feed bunk seen in dominant heifers.

2.5 Conclusions

Feed delivery method affects the feeding, sorting, and competitive behaviour of growing dairy heifers. Heifers fed the TDR consumed less NDF, showed greater feed bunk competition, and displayed more liquid fecal consistency. Feeding a TMR to replacement dairy heifers promoted a more even diurnal feeding pattern, minimized sorting and competitive behaviour, and resulted in more solid fecal consistency. Further research is needed to determine when these behaviours develop and how long they may persist in the life of the animal.

2.6 Acknowledgements

We thank the staff and students at the University of Guelph, Kemptville Campus Dairy Education and Research Centre. In particular, we thank Megan Bruce, Albert Koekkoek, Emily Miller-Cushon, and Hauke Timm for their help with the project. Angela Greter was supported by a Natural Sciences and Engineering Research Council of Canada (NSERC) Post-Graduate Scholarship. This project was funded by an NSERC Collaborative Research Development Grant with the Dairy Farmers of Canada and received support from the Ontario Ministry of Agriculture, Food and Rural Affairs.
Table 2.1. Chemical composition and particle size distribution of the experimental ration and components.

<table>
<thead>
<tr>
<th>Composition</th>
<th>Concentrate$^1$</th>
<th>Haylage</th>
<th>Ration$^{2,3}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical composition$^4$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DM, %</td>
<td>91.8 ± 0.4</td>
<td>41.9 ± 2.3</td>
<td>53.3 ± 4.1</td>
</tr>
<tr>
<td>OM, % of DM</td>
<td>90.5 ± 1.0</td>
<td>90.7 ± 1.2</td>
<td>91.5 ± 0.7</td>
</tr>
<tr>
<td>CP, % of DM</td>
<td>20.2 ± 1.7</td>
<td>19.7 ± 1.0</td>
<td>19.4 ± 0.4</td>
</tr>
<tr>
<td>ADF, % of DM</td>
<td>9.0 ± 0.5</td>
<td>34.1 ± 2.1</td>
<td>25.4 ± 3.0</td>
</tr>
<tr>
<td>NDF, % of DM</td>
<td>20.9 ± 0.7</td>
<td>42.9 ± 2.4</td>
<td>35.2 ± 2.7</td>
</tr>
<tr>
<td>NFC, % of DM</td>
<td>42.9 ± 2.4</td>
<td>26.3 ± 2.6</td>
<td>34.9 ± 3.2</td>
</tr>
<tr>
<td>Particle size, %$^5$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Long</td>
<td>-</td>
<td>20.3 ± 4.2</td>
<td>10.8 ± 3.6</td>
</tr>
<tr>
<td>Medium</td>
<td>-</td>
<td>46.7 ± 5.6</td>
<td>43.0 ± 5.3</td>
</tr>
<tr>
<td>Short</td>
<td>-</td>
<td>30.3 ± 2.1</td>
<td>41.0 ± 5.7</td>
</tr>
<tr>
<td>Fine</td>
<td>-</td>
<td>2.8 ± 0.5</td>
<td>5.2 ± 1.4</td>
</tr>
</tbody>
</table>

$^1$ Supplied by Rooney Feeds Ltd. (Iroquois, ON, Canada), containing (on as-is basis): 34.7% steam-flaked corn, 34.0% whole barley, 15.0% dairy supplement premix (40% protein), 9.0% hi-protein soymeal, 3.5% Monensin pellet, 1.5% molasses, 1.0% dicalcium phosphate, 0.5% calcium carbonate, 0.5% salt, and 0.3% magnesium oxide.  
$^2$ Containing, on a DM basis, 35% concentrate and 65% grass/alfalfa haylage.  
$^3$ Chemical composition (DM basis) of long particles was 44.2 ± 1.5% NDF and 3.1 ± 0.5% starch, medium particles was 33.5 ± 2.9% NDF and 16.9 ± 2.3% starch, short particles was 32.6 ± 1.5% NDF and 17.0 ± 1.8% starch, and fine particles was 25.5 ± 2.3% NDF and 15.6 ± 3.4% starch.  
$^4$ Values were obtained from chemical analysis of TMR samples. OM = 100 - %ash. NFC = 100 - (%CP + %NDF + %fat + %ash).  
$^5$ Particle size determined by Penn State Particle Separator which has a 19 mm screen (long), 8 mm screen (medium), 1.18 mm screen (short) and a pan (fine).

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Table 2.2. Intake and behaviour measures from growing dairy heifers on experimental treatments.

<table>
<thead>
<tr>
<th>Item</th>
<th>Treatment^2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TMR</td>
</tr>
<tr>
<td>Feeding time, min/d</td>
<td>199.7</td>
</tr>
<tr>
<td>Peak feeding time^3, min/d</td>
<td>32.0</td>
</tr>
<tr>
<td>Displacements, no./d</td>
<td>8.6</td>
</tr>
<tr>
<td>Peak displacements^3, no./d</td>
<td>1.9</td>
</tr>
<tr>
<td>Lying time, h/d</td>
<td>14.3</td>
</tr>
<tr>
<td>Lying bouts, no./d</td>
<td>14.6</td>
</tr>
<tr>
<td>Fecal score</td>
<td>3.4</td>
</tr>
<tr>
<td>DMI, kg/d</td>
<td>7.36</td>
</tr>
<tr>
<td>NDF intake, kg/d</td>
<td>2.61</td>
</tr>
<tr>
<td>ADG, kg/d</td>
<td>1.27</td>
</tr>
<tr>
<td>ADGv^4, kg/d</td>
<td>0.20</td>
</tr>
</tbody>
</table>

^1Data are averaged across 4 pens (4 heifers/pen) on each treatment.

^2On a DM basis, 35 % concentrate fed top-dressed (TDR) on or mixed with (TMR) 65% grass/alfalfa haylage.

^3Peak feeding activity period = 2-h period immediately following feed delivery.

^4ADGv= pen variance of average daily gain. ADGv was calculated by averaging, per pen, the absolute difference between individual heifer ADG and pen mean ADG.
Table 2.3. Effect of experimental treatments on the sorting (%) of long, medium, short, and fine particles by growing dairy heifers$^{1,2}$.

<table>
<thead>
<tr>
<th>Particles$^4$</th>
<th>Treatment$^3$</th>
<th>TMR</th>
<th>TDR</th>
<th>SE</th>
<th>$P$-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long</td>
<td>98.9$^*$</td>
<td>96.0$^*$</td>
<td>0.5</td>
<td></td>
<td>0.006</td>
</tr>
<tr>
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<td>100.1</td>
<td>99.4$^*$</td>
<td>0.1</td>
<td></td>
<td>0.002</td>
</tr>
<tr>
<td>Short</td>
<td>100.3$^*$</td>
<td>101.1$^*$</td>
<td>0.1</td>
<td></td>
<td>0.004</td>
</tr>
<tr>
<td>Fine</td>
<td>97.5$^*$</td>
<td>101.2$^*$</td>
<td>0.4</td>
<td></td>
<td>$&lt;0.001$</td>
</tr>
</tbody>
</table>

$^1$Sorting % = 100 x (particles size n DM intake/particle size n predicted intake). Sorting values equal to 100% indicate no sorting, <100% indicate selective refusals (sorting against), and >100% indicate preferential consumption (sorting for). Data are averaged across 28 d for 4 pens (4 heifers/pen) on each treatment.

$^2$Difference in sorting values from 100% expressed as: $^* P < 0.05$

$^3$On a DM basis, 35% concentrate fed top-dressed (TDR) on or mixed with (TMR) 65% grass/alfalfa haylage.

$^4$Particle size determined by Penn State Particle Separator, which has a 19-mm screen (long), 8-mm screen (medium), 1.18-mm screen (short), and a pan (fine).
Figure 2.1. Percentage of heifers present at the feed bunk over a 24-h period (percentage for each 10-min interval during the day) for 2 treatments: 1) TMR and 2) top-dressed ration (TDR). Data were averaged across 28 d for 4 pens (4 heifers/pen) per treatment.
Figure 2.2. Sorting activity ([100 x (long particle intake/long particle predicted intake)]) of heifers on a TMR or a top-dressed ration (TDR) for long particles (>19 mm). Data were averaged across the 7 d of each period with 4 pens (4 heifers/pen) per treatment. Sorting values equal to 100% indicate no sorting, <100% indicate selective refusals (sorting against), and >100% indicate preferential consumption (sorting for).
CHAPTER 3: FEED DELIVERY METHOD AFFECTS THE LEARNING OF FEEDING AND COMPETITIVE BEHAVIOUR IN DAIRY HEIFERS

3.1 Introduction

Learning and development of feeding behaviour patterns occurs in animals as a result of experience with different foods, including post-ingestive feedback (Burritt and Provenza, 1990; Provenza, 1995b), as well as through social interactions (Ralphps et al., 1994). Researchers have also shown that animals learn dietary patterns and habits from a young age (Provenza and Balph, 1987). For example, Nolte et al. (1990) demonstrated that young lambs exposed to wheat for 60-d showed a later preference for wheat when offered a choice between wheat and barley. This suggests that lambs exposed to a food early in life may have learned from the feeding event, reinforced by the positive experience of ingesting a palatable and nutritious food, resulting in continued ingestion of that familiar food. Given that this type of learning may occur from a young age, and that animals prefer to consume familiar foods in familiar situations (Arnold and Maller, 1977), it follows that animals may acclimate more readily to a new ration when presented with feed in a similar form to that experienced as a young animal.

Adult dairy cattle often exhibit feeding behaviours that may be undesirable, such as feed sorting (Leonardi and Armentano, 2003; DeVries et al., 2008), slug feeding (rapid intake) of the concentrate component of a ration (Maekawa et al., 2002), or competitive interactions (Herlin and Frank, 2007; González et al., 2008). These feeding patterns can lead to metabolic disorders, such as sub-acute ruminal acidosis, due to excessive consumption of rapidly degradable carbohydrates and lack of effective fiber consumption, often resulting in diarrhea (Krause and Oetzel, 2006: DeVries et al., 2008). It is possible that these feeding behaviour patterns develop as a result of learning that
occurs early in life. Researchers have recently shown that young dairy heifers exposed to roughage and concentrate in either a top-dressed ration (TDR) or as separate components sort more, consume the concentrate in a slug feeding pattern, compete more for feed, and have looser fecal consistency than animals presented with the same diet mixed together as a TMR (DeVries and von Keyserlingk, 2009a; Greter et al., in press). If such behaviour persists into adult life, then the animal is poorly set up to deal with the challenges of the lactating herd, such as feed bunk competition, low forage rations, and other dietary changes. It may be, therefore, a positive management decision to provide a TMR to dairy cattle from a very young age to ensure easier transitions throughout growth and development of the animal, and to possibly prevent or minimize such undesirable feeding patterns or behaviours from developing.

The objective of this study was to determine how different feeding methods (TDR vs. TMR) may affect the learning of feeding and sorting behaviour, and feeding competition of growing dairy heifers. Our hypotheses were that heifers previously fed a TMR would distribute their feeding time more evenly throughout the day, sort the new ration less, compete less for feed, maintain a more solid fecal consistency, and continue to grow rapidly due to balanced nutrient intake in comparison to heifers previously fed a top dressed ration.

3.2 Materials and Methods

3.2.1 Animals and Housing

Thirty-two Holstein dairy heifers were used in this study and were acquired, on loan, from a local commercial dairy operation. The animals were (mean ± SD) 237.2 ± 21.9 d old, weighed 264.6 ± 29.6 kg (235.0-294.2 kg), and measured 117.6 ± 3.2 cm (114.4-120.8 cm) high at the withers at the beginning of the experiment. Heifers were
given a 12-d adaptation period following arrival at the research facilities. During the adaptation period, dietary components were fed separately to prevent sorting behaviour. The heifers were housed in groups of 4 in 8 pens in the heifer research barn at the University of Guelph, Kemptville Campus (Kemptville, ON, Canada) and were managed according to the guidelines set by the Canadian Council on Animal Care (1993). Use of animals was approved by the University of Guelph’s animal care committee (AUP#08R011). The pens, located in a naturally ventilated cold barn, consisted of an indoor sawdust-bedded pack area (3.6 m x 10.9 m) and an outdoor concrete run (3.6 m x 16.4 m). Bedding material was replenished as needed. Feed bunks were located along the front of each pen and measured 1.35 m in length, allowing for 0.34 m of open bunk space per animal. There were no head-gates or vertical barriers used at the feed bunk. The animals were given ad libitum access to feed. Orts were cleaned out of the feed bunks at 1030h each day, with new feed delivered once daily at 1200h. Water was available ad libitum through a water bowl in each pen. Heifers were also given ad libitum access to trace mineral salt blocks (Windsor TM Stock Salt, The Canadian Salt Company Limited, Pointe-Claire, QC).

3.2.2 Experimental Design and Diets

Heifers were divided into 8 groups of 4 (balanced on weight and age upon arrival to the facility) and exposed to 1 of 2 dietary treatments for 13 weeks, according to Greter et al. (in press). The treatment diets were: 1) total mixed ration (TMR) and 2) top-dressed ration (TDR). The initial treatment diets both contained 65% grass/alfalfa haylage and 35% of a textured concentrate. Immediately following the 13-week period, all pens were switched to an unfamiliar TMR for an additional 7 weeks. Heifers remained in the same pens with the same group of individuals. The TMR was prepared daily in a mixer wagon and manually weighed into the feed bunk in each pen. The amount of feed
offered was adjusted daily to ensure 5-10% orts. The actual orts averaged 5.6 ± 3.4% DM of the offered feed over the 7 weeks while heifers were on the unfamiliar TMR. The ingredient and chemical composition of the ration is given in Table 3.1.

3.2.3 Experimental Measurements

Group intakes were recorded daily throughout the 7 weeks of the study by weighing the amount of feed offered and the amount of feed refused. These data were used to calculate daily DMI (kg/d) on a pen basis. Heifers were weighed and measured on the same weekday at the same time every 2 wks to measure weight gain and growth (height). Additionally, animals were fecal scored for consistency of feces twice weekly using a scale from 1 (liquid) to 4 (solid; Ireland-Perry and Stallings, 1993).

Feeding behaviour and feeding competition were monitored using time-lapse video equipment. Feeding time and social aggression at the feed bunk were recorded continuously for all 7 d of each recording week: weeks 1, 4, and 7 of the study. Animals were recorded using 1 video camera (Panasonic WV-BP330; Osaka, Japan) per 2 pens, a time-lapse video cassette recorder (Panasonic AG-6740), and a video multiplexer (Panasonic WJ-FS 616). Video cameras were located 3.2 m above the feed bunk, between two pens. Red lights (100 W), hung adjacent to the cameras, were used to facilitate recording at night. Individual animals were identified within each pen with unique neck collars.

The amount of time spent feeding during all 7 d of each recording week was scored for individual heifers from video using instantaneous scan sampling every 10 min. For each scan, an animal was recorded as feeding when its head was completely past the feed rail and over the feed. These scans were then used to calculate the total time spent feeding by multiplying the number of scans by 10 (Endres et al., 2005). Time spent
feeding was then calculated for each heifer for each day of the recording weeks (min/d). Additionally, to detect changes in the diurnal pattern of feed bunk attendance, these scans were used to calculate the percentage of heifers at the feed bunk over the course of each 24-h period. Based on these diurnal patterns, we also calculated feeding time for each heifer during the 120-min period (peak feeding time) following the delivery of feed when feeding activity was highest.

Feeding competition, recorded as displacements from the feed bunk while feeding, was measured on d 2, 4, and 6 of each recording week. A displacement was noted when a butt or a push from the actor (instigator) resulted in the complete withdrawal of the reactor's head from beneath the feed rail (DeVries et al., 2004). These observations were used to calculate, according to DeVries et al. (2004), an agonistic interaction success rate (AISR) for each individual heifer. A successful interaction occurs when one heifer (dominant) successfully manages to completely displace another (subdominant) from the feed bunk. The heifers were classed as being either above or below the focal animal in rank. The AISR was calculated as follows: number of individuals subdominant to focal heifer / number of individuals dominant to focal heifer + number of individuals subdominant to focal heifer x 100%.

3.2.4 Feed Sampling and Analysis

A representative sample of the ration was collected for particle size separation at feed delivery each day during the recording weeks. Orts samples, for particle size separation, were taken from each feed bunk at the end of each recording day. Samples of the TMR and orts from each pen were taken twice weekly throughout the experiment for DM and chemical analysis, as well as to determine NDF intakes. Samples of the dietary components were also taken once a week for DM and chemical analysis.
Duplicate samples of forage components were taken during the recording weeks to allow for particle size analysis. All samples were immediately frozen at -20°C until they were further analyzed.

Samples for particle size separation were separated using the 3-screen (19, 8, 1.18 mm) Penn State Particle Separator (PSPS; Kononoff et al., 2003). This separated the samples into 4 fractions: long (>19 mm), medium (<19, >8 mm), short (<8, >1.18 mm), and fine (<1.18 mm) particles. After separation, the DM of each separated fraction was determined by oven drying at 55 ºC for 48 h. The percentage of each fraction in the ration and forage components is given in Table 3.2.

Dry matter content of samples taken for chemical analysis was determined by drying samples in a forced-air oven at 55 ºC for 48 h. These samples were then ground to pass through a 1-mm screen (Wiley Mill, Arthur H. Thomas Co., Philadelphia, PA). These samples, plus the dried TMR particle fractions, were sent to Cumberland Valley Analytical Services Inc. (Maugansville, MD, USA) for analysis of DM (135ºC; AOAC, 2000: method 930.15), ash (535ºC; AOAC, 2000: method 942.05), ADF (AOAC, 2000: method 973.18), NDF with heat-stable α-amylase and sodium sulfite (Van Soest et al., 1991), CP (N x 6.25) (AOAC 2000: method 990.03; Leco FP-528 Nitrogen Analyzer, Leco, St. Joseph, MI) and starch (Holm et al., 1986).

3.2.5 Calculations and Statistical Analysis

Sorting was calculated as the actual DMI of each fraction of PSPS, expressed as a percentage of the predicted DMI of that fraction (Leonardi and Armentano, 2003). The actual intake of each individual fraction was calculated as the difference between the DM amount of each fraction in the offered feed and that in the refused feed. The predicted intake for each individual fraction was calculated as the product of the DMI of the total...
diet multiplied by the DM percentage of that fraction in the offered diet. Values equal to 100% indicate no sorting, <100% indicate selective refusals (sorting against), and >100% indicate preferential consumption (sorting for).

Preliminary screening of the data revealed that all dependent variables were normally distributed. For analyses of treatment effects, the pen was considered as the experimental unit. The DMI and sorting behaviour data were calculated on a pen basis and averaged by week for the entire experiment. Weight gain and growth were averaged on a pen basis by two-week period for the entire experiment. Feeding, social, and lying behaviour data were averaged across heifers within each pen and days to create one observation per recording week per pen. Data for feed bunk attendance (% of heifers feeding) were summarized by hour for each pen on each treatment.

To test whether sorting of the experimental diets occurred, data for each PSPS fraction were averaged across each recording week for each pen and tested for a difference from 100 using t-tests within the MIXED procedure of SAS (2003). To test for the effect of treatment, all data were analyzed using the MIXED procedure of SAS (2003) treating week as a repeated measure. Appendix 1 provides examples of the SAS codes used for these analyses. The model included the fixed effects of treatment and week and the random effect of pen within treatment. The variance-covariance error structure was compound symmetry, variance components, or heterogeneous compound symmetry, depending upon best fit according to Schwarz’s Bayesian information criterion. To test for effect of treatment on feed bunk attendance patterns, these data were analyzed using the MIXED procedure of SAS (2003) treating hour as a repeated measure. The model included the fixed effects of treatment and hour and the random effect of pen within treatment. The variance-covariance structure was first-order
autoregressive, according to best fit with Schwarz's Bayesian information criterion. All values reported are least squares means ± standard error.

To test the hypothesis that socially subordinate heifers would be most affected in their response to the treatments, measures of weight gain, growth, feeding time, peak feeding time, and fecal score were regressed within treatment on the heifer's AISR using the regression procedure of SAS (2003). Only those statistically significant models are shown. Unless presented, there were no time*treatment interactions. For all analyses, significance was declared at $P \leq 0.05$, and a trend was reported if $0.05 < P \leq 0.10$.

3.3 Results

Analysis of the diurnal feed bunk attendance of heifers showed a treatment by hour interaction ($SE = 0.6$, $P < 0.001$; Figure 3.1), with a greater percentage of heifers previously fed the TDR present at the feed bunk during the 2 h after feed delivery (period of peak feeding activity). During the peak feeding time period, heifers previously fed the TDR spent more time at the feed bunk than heifers previously fed the TMR (Table 3.3). Over the whole day, this resulted in a tendency for the heifers previously fed the TDR to have longer feeding times (Table 3.3). The AISR was negatively related to feeding time ($y = -0.3x + 202.3; R^2 = 0.28, P = 0.03$) and tended to be negatively related to peak feeding time ($y = -0.1x + 29.3; R^2 = 0.23, P = 0.06$) for heifers previously fed the TMR, whereas there was no relationship between AISR and feeding time or peak feeding time for heifers previously fed the TDR. The number of displacements, as measured by the number of times a heifer was physically displaced from the feed bunk, was greater for animals previously fed the TDR than for those previously fed the TMR, particularly during the period of peak feeding activity (Table 3.3).

41
Heifers sorted against long particles (>19 mm) on both treatments (Table 3.4). There was, however, no difference in the extent of this sorting between treatments. Animals did not sort for or against medium particles on either treatment (Table 3.4). Heifers previously fed the TDR tended to sort against short particles while heifers fed the TMR ration did not sort for or against short particles (Table 3.4). Heifers previously fed the TDR sorted against fine particles, whereas heifers fed the TMR ration tended to sort against fine particles (Table 3.4). As a result, there was a weak tendency for a difference between treatments for sorting of short and fine particles.

Heifers previously fed the TDR had more fluid feces than those fed the TMR (Table 3.3). Dry matter intake did not differ between treatments (Table 3.3). Average daily gain was also similar between treatments (Table 3.3).

3.4 Discussion

In support of our hypothesis we found that heifers previously fed a TMR distributed their feeding time more evenly throughout the day, while heifers previously fed a TDR showed a greater peak in feeding activity following feed delivery. Heifers previously fed the TDR spent over 60% more time at the feed bunk during peak feeding activity, which translated to 12% more heifers present at the feed bunk. This is similar to what was seen during the first 13 weeks of the experiment, where heifers fed the TDR spent over 60% more time at the feed bunk with 15% more heifers present at the feed bunk during peak feeding activity (Greter et al., in press). In fact, the diurnal feeding pattern for all heifers was very similar to that seen during the first 13 weeks of the experiment, when animals were fed using different feeding methods. It can, therefore, be suggested that the animals had learned to feed in a particular pattern during the first 13 weeks, and that these animals retained that pattern across the ration change.
Furthermore, these feeding patterns persisted through the 7 weeks of the experiment, suggesting that the animals had not only learned particular feeding patterns, but that these patterns were continual and may be difficult to alter or extinguish over time. It was likely that, during the first 13 weeks of the experiment, heifers fed a TDR were spending more time at the feed bunk during peak feeding activity due to the rapid consumption of the readily available concentrate component of the ration (Greter et al., in press). As such, it is likely that heifers previously fed the TDR continued to spend more time at the feed bunk during the period of peak feeding activity simply as a result of previous feeding patterns, in which these animals were consuming large amounts of their grain concentrate during this time period (Greter et al., in press). It can be hypothesized that the heifers then learned from and became conditioned to the feeding experience, and, as a result, continued to utilize these feeding patterns when switched to an unfamiliar ration.

We also found, in support of our hypothesis, that the heifers previously fed the TMR competed less for their feed than heifers previously fed the TDR, engaging in half the number of displacements. This translated into these heifers being displaced 40% more often than heifers fed the TMR during the period of peak feeding activity. Additionally, heifers previously fed the TDR performed a greater percentage of their daily displacements (35%) during this time period than heifers previously fed the TMR (24%). These results are similar to that seen when heifers were fed using different feeding methods, wherein the heifers fed the TDR performed a greater percentage (37%) of their daily displacements during the period of peak feeding activity than heifers fed the TMR (22%; Greter et al., in press). It should be noted that stocking density at the feed bunk was not excessive (Longenbach et al., 1999), and that, in a situation of high stocking density, the effects seen here may have been exacerbated (DeVries and von
Keyserlingk, 2009b). Interestingly, heifers previously fed the TDR were unaffected by dominance status in their feeding patterns, as opposed to heifers previously fed the TMR who were affected. This suggests that, despite the fact that all animals were given the same ration using the same feeding method, the motivation to consume the ration remained strong in all heifers previously fed the TDR and that even subordinate animals were motivated to compete openly for feed, particularly during the period of peak feeding. This provides further evidence that competitive feeding behaviour pattern became habitual in these animals. Habits are learned behaviours that become resistant to extinction or alteration by changes in outcome (Adams and Dickinson, 1981). The competition seen in heifers fed the TDR during the first 13 weeks would have resulted in occasional rewards of larger amounts of concentrate (since the concentrate component was more readily available than in the TMR) when interactions were successful.

Research has shown that intermittent reinforcement is known to induce habit formation in rats (Wojnicki et al., 2007). As such, this competitive behaviour would be intermittently reinforced and this may offer further explanation as to why the behaviour did not extinguish across the ration change and became habitual (Theios, 1962).

In further support of our hypothesis, heifers previously fed the TDR continued to exhibit lower, loose fecal scores throughout the course of the experiment compared to heifers previously fed the TMR. These fecal scores were similar to that observed during the first part of the experiment (Greter et al., in press). We can speculate that the looser feces were the result of rumen fermentation problems, possibly due to the continuation of slug feeding patterns. Slug feeding of concentrate or of TMR may result in large postprandial drops in rumen pH and cause diarrhea (Nocek, 1997; Kleen et al. 2003; Krause and Oetzel, 2006). Heifers previously consuming a TMR from a young age, conversely, demonstrated a more balanced feeding pattern throughout the day and had
more normal fecal consistency. The continuation of this through the ration change indicates that these animals were conditioned to this feeding pattern.

Contrary to our hypothesis, the sorting behaviour of the heifers was similar between treatment groups after the dietary change. It was expected that heifers previously fed the TDR would actively sort for the short particle fraction of the ration, as this fraction primarily contained the concentrate component of the ration, something that these animals had previously sorted and competed heavily for during the period of peak feeding activity (Greter et al., in press). Alternatively, given that the difference in sorting between feeding methods had disappeared by the final week of the first 13 weeks of the experiment (Greter et al., in press), it may not be surprising that the sorting behaviour was similar for all heifers when changed to the new ration. There also was no difference in DMI between treatments, which could be expected since all animals were fed the same ration and no difference in DMI had been observed during the first 13 weeks of the experiment (Greter et al., in press).

Further, contrary to our hypothesis, there was also no difference in ADG between treatments. However, the lack of difference in gain between treatments is surprising, since the fecal scores were different between treatments. Similar results in gain were also seen during the first 13 weeks of the experiment (Greter et al., in press), and it was speculated there that these animals may have been able to acclimate to depressing conditions and balance resources to maintain gain, something that has been known to occur in adult animals experiencing similar challenges (O'Grady et al., 2008). However, it is hypothesized that this ability to acclimate may be short-term, and that the heifers previously fed a TDR would not be able to maintain, in the long-term, a similar ADG to those fed the TMR. Results from this experiment show otherwise, suggesting that the
fecal consistency difference was not large enough to indicate any major physiological changes across treatments.

Overall, this research provides interesting insight into the learning of behavioural patterns in young dairy heifers. Further research in this area is still needed to assist in the development of management protocols that would help to cultivate the learning of desirable behaviour and prevent detrimental feeding patterns from developing. It still needs to be determined how long learned feeding patterns may persist in the life of the animal. In addition, it is unknown if these behaviours could be extinguished or altered over time or through further learning experiences, particularly when entering the lactating herd and presented with the challenges of frequent ration changes, group changes, and production stress. Furthermore, the persistence of these undesirable behaviours may put the cow at a disadvantage later in life if she should lose the ability to be flexible in her feeding behaviour and no longer able to acclimate readily to changes in situation or physiological state (Kyriazakis et al., 1999). Future research on the flexibility of feeding behaviour and the possible impact on the internal state of the animal over time would be helpful in determining the long-term effects of feeding patterns and habits. It was not possible to measure rumen pH in this study. Thus, further research is needed to determine if the feeding patterns that developed truly did disrupt normal rumen fermentation. Finally, the lack of sorting difference following the ration change was quite surprising. Further research on the learning of sorting behaviour is needed, particularly considering when and how this behaviour develops, as it would appear that feeding method has little impact on the development of feed sorting behaviour in pre-pubertal dairy heifers.

3.5 Conclusions
Long-term exposure to these feeding methods affected the learning of feeding and competitive behaviour in growing dairy heifers. The diurnal feeding activity pattern, increased feed bunk competition, and less solid fecal consistency suggest that heifers previously fed a TDR had developed undesirable and possibly detrimental behavioural patterns. Alternatively, it can be concluded that feeding a TMR from a young age to replacement dairy heifers results in long-term behavioural patterns that promote a more even diurnal feeding pattern, minimize feed bunk competition, and promote a more solid fecal consistency, thus improving the overall welfare of these animals.

3.6 Acknowledgements

We thank the staff and students at the University of Guelph, Kemptville Campus Dairy Education and Research Centre. In particular, we thank Megan Bruce, Albert Koekkoek, Emily Miller-Cushon, and Hauke Timm for their help with the project. Angela Greter was supported by a Natural Sciences and Engineering Research Council of Canada (NSERC) Post-Graduate Scholarship. This project was funded by an NSERC Collaborative Research Development Grant with the Dairy Farmers of Canada and received support from the Ontario Ministry of Agriculture, Food and Rural Affairs.
Table 3.1. Ingredient and chemical composition of the treatment diet.

<table>
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<th>Composition</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Ingredient, %DM</td>
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</tr>
<tr>
<td>Corn silage(^1)</td>
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</tr>
<tr>
<td>Grass/alfalfa haylage(^2)</td>
<td>21.0</td>
</tr>
<tr>
<td>High moisture corn(^3)</td>
<td>21.0</td>
</tr>
<tr>
<td>Mineral premix(^4)</td>
<td>1.9</td>
</tr>
<tr>
<td>Chemical composition(^5)</td>
<td></td>
</tr>
<tr>
<td>DM, %</td>
<td>52.1 ± 1.4</td>
</tr>
<tr>
<td>OM, % of DM</td>
<td>92.9 ± 0.2</td>
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<tr>
<td>CP, % of DM</td>
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<tr>
<td>ADF, % of DM</td>
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<tr>
<td>NDF, % of DM</td>
<td>37.8 ± 1.2</td>
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<tr>
<td>NFC, % of DM</td>
<td>39.0 ± 1.3</td>
</tr>
<tr>
<td>Starch, % of DM</td>
<td>22.3 ± 2.0</td>
</tr>
</tbody>
</table>

\(^1\)Chemical composition of corn silage (DM basis) was 8.2 ± 0.0% CP, 21.7 ± 0.9% ADF, and 37.0 ± 0.9% NDF.

\(^2\)Chemical composition of grass/alfalfa haylage (DM basis) was 17.5 ± 0.6% CP, 33.6 ± 0.5% ADF, and 47.3 ± 1.5% NDF.

\(^3\)Chemical composition of high moisture corn (DM basis) was 8.8 ± 0.1% CP, 3.7 ± 0.1% ADF, and 12.6 ± 0.2% NDF.

\(^4\)Supplied by Rooney Feeds Ltd. (Kemptville, ON, Canada), containing (on as-is basis): 14.0% calcium, 7.8% sodium, 6.5% phosphorus, 2.3% potassium, 1.0% magnesium, 0.28% sulfur, 0.16% lasalocid sodium, 5 760 mg/kg iron, 4 000 mg/kg zinc, 3 200 mg/kg manganese, 980 mg/kg copper, 500 mg/kg fluorine, 80 mg/kg iodine, 20 mg/kg cobalt, 320 000 I.U./kg vitamin A, 48 000 I.U./kg vitamin D3, and 800 I.U./kg vitamin E.

\(^5\)Values were obtained from chemical analysis of TMR samples. OM = 100 - %ash. NFC = 100 - (%CP + %NDF + %fat + %ash).
<table>
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<tr>
<th>Particle Size&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Grass/Alfalfa Haylage</th>
<th>Corn Silage</th>
<th>Ration&lt;sup&gt;2&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long</td>
<td>17.6 ± 4.3</td>
<td>5.4 ± 3.4</td>
<td>6.6 ± 2.4</td>
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<tr>
<td>Medium</td>
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<td>54.7 ± 2.4</td>
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<td>Short</td>
<td>29.4 ± 0.9</td>
<td>31.0 ± 8.1</td>
<td>31.6 ± 1.9</td>
</tr>
<tr>
<td>Fine</td>
<td>5.3 ± 1.1</td>
<td>3.5 ± 1.8</td>
<td>7.1 ± 0.9</td>
</tr>
</tbody>
</table>

<sup>1</sup> Particle size determined by Penn State Particle Separator which has a 19 mm screen (long), 8 mm screen (medium), 1.18 mm screen (short) and a pan (fine).

<sup>2</sup> Chemical composition (DM basis) of long particles was 47.3 ± 2.3% NDF and 5.2 ± 1.3% starch, medium particles was 37.3 ± 0.9% NDF and 23.5 ± 0.8% starch, short particles was 34.7 ± 0.6% NDF and 22.4 ± 0.7% starch, and fine particles was 25.4 ± 3.6% NDF and 31.0 ± 2.5% starch.
Table 3.3. Intake and behaviour measures from growing dairy heifers on experimental treatments.¹

<table>
<thead>
<tr>
<th>Item</th>
<th>Treatment²</th>
<th>TMR</th>
<th>TDR</th>
<th>SE</th>
<th>P-value</th>
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<tbody>
<tr>
<td>Feeding time, min/d</td>
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<td>0.06</td>
</tr>
<tr>
<td>Peak feeding time², min/d</td>
<td>25.9</td>
<td>40.6</td>
<td>3.8</td>
<td></td>
<td>0.03</td>
</tr>
<tr>
<td>Displacements, no./d</td>
<td>13.1</td>
<td>23.0</td>
<td>1.8</td>
<td></td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Peak displacements², no./d</td>
<td>3.2</td>
<td>8.0</td>
<td>0.7</td>
<td></td>
<td>0.002</td>
</tr>
<tr>
<td>Fecal score</td>
<td>3.7</td>
<td>3.2</td>
<td>0.1</td>
<td></td>
<td>0.02</td>
</tr>
<tr>
<td>DMI, kg/d</td>
<td>8.9</td>
<td>9.1</td>
<td>0.3</td>
<td></td>
<td>0.6</td>
</tr>
<tr>
<td>Growth rate, kg/d</td>
<td>1.2</td>
<td>1.1</td>
<td>0.07</td>
<td></td>
<td>0.3</td>
</tr>
</tbody>
</table>

¹Data are averaged across 4 pens (4 heifers/pen) on each treatment.
²Peak feeding activity period = 2-h period immediately following feed delivery.
³Heifers were previously fed, on a DM basis, 35 % concentrate fed top-dressed (TDR) on or mixed with (TMR) 65% grass/alfalfa haylage for 13 weeks.
Table 3.4. Effect of experimental treatments on the sorting (%) of long, medium, short, and fine particles by growing dairy heifers\textsuperscript{1,2}.

<table>
<thead>
<tr>
<th>Particles\textsuperscript{4}</th>
<th>Treatment\textsuperscript{3}</th>
<th>TMR</th>
<th>TDR</th>
<th>SE</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long</td>
<td></td>
<td>91.6*</td>
<td>93.2*</td>
<td>2.1</td>
<td>0.6</td>
</tr>
<tr>
<td>Medium</td>
<td></td>
<td>99.9</td>
<td>99.9</td>
<td>0.2</td>
<td>0.9</td>
</tr>
<tr>
<td>Short</td>
<td></td>
<td>100.0</td>
<td>99.6*</td>
<td>0.2</td>
<td>0.1</td>
</tr>
<tr>
<td>Fine</td>
<td></td>
<td>99.4†</td>
<td>98.4*</td>
<td>0.3</td>
<td>0.1</td>
</tr>
</tbody>
</table>

\textsuperscript{1}Sorting % = 100 x (particles size n DM intake/particle size n predicted intake). Sorting values equal to 100% indicate no sorting, <100% indicate selective refusals (sorting against), and >100% indicate preferential consumption (sorting for). Data are averaged across 21 d for 4 pens (4 heifers/pen) on each treatment.

\textsuperscript{2}Difference in sorting values from 100% expressed as: * $P < 0.05$, † $P < 0.10$

\textsuperscript{3}Heifers were previously fed, on a DM basis, 35 % concentrate fed top-dressed (TDR) on or mixed with (TMR) 65% grass/alfalfa haylage for 13 weeks.

\textsuperscript{4}Particle size determined by Penn State Particle Separator, which has a 19-mm screen (long), 8-mm screen (medium), 1.18-mm screen (short), and a pan (fine)
Figure 3.1. Percentage of heifers present at the feed bunk over a 24-h period (percentage for each 10-min interval during the day) for 2 treatments: 1) Heifers previously fed a TMR and 2) Heifers previously fed a top dressed ration. Data were averaged across 21 d for 4 pens (4 heifers/pen) per treatment.
CHAPTER 4: GENERAL DISCUSSION

4.1 Important Findings

Advances in nutrition, health, and overall management of dairy cattle have been made in the past few decades. Recent research has been focused on understanding the role that knowledge of dairy cattle behaviour can play in the improvement of health and management strategies (von Keyserlingk et al., 2009). It has been suggested that feeding behaviours, patterns, and habits, which can affect the health and production of mature cattle, may develop early in the life of the ruminant (Provenza and Balph, 1987). The research described in this dissertation was conducted to better understand the influence of feeding method on the learning of these behaviours in dairy heifers. The results from this thesis represent some of the first experiments to demonstrate a relationship between early feeding experiences and learning of behavioural patterns of dairy cattle in an intensive farming situation. In particular, it was found that heifers fed a TMR from a young age were able to more evenly distribute their feeding activity throughout the day, compete less for feed, and maintain more solid fecal consistency than heifers fed a TDR. These results persisted across a ration change to an unfamiliar TMR, suggesting that learning of these behavioural patterns had occurred.

Feeding of a TDR to young dairy heifers resulted in greater activity at the feed bunk after feed delivery, suggesting that these heifers rapidly consumed the concentrate component of the diet (slug feeding). This, in turn, could potentially result in problems associated with postprandial drops in rumen pH such as sub-acute ruminal acidosis (SARA). Conversely, heifers fed the TMR spread their feeding activity more evenly throughout the day, and thus, likely experienced fewer and less severe fluctuations in rumen pH. Of particular interest, this feeding pattern persisted through a ration change,
suggesting that this feeding pattern was learned through conditioning. Furthermore, competition for feed was much greater in animals fed the TDR than in animals fed the TMR, likely due to a higher motivation to consume the highly palatable concentrate component of the ration, which was easily accessible in the TDR. Interestingly, this behaviour also persisted across the ration change, again suggesting that the animals had been conditioned to a feeding experience (higher levels of competition). Thus, although they had been competing for a particular resource during the first 13 weeks, the heifers continued to behave in a similar fashion, despite the resource now being more difficult to consume. This suggests that these behaviours had become habitual and that there was some resistance to extinction of this behavioural pattern through the ration change. Interestingly, the combined effects of these behaviours seemed to impact the fecal consistency of the heifers, with animals fed the TMR maintaining more solid feces throughout the course of the experiment. Loose feces can be used as an indicator of problems with rumen/digestive health (Nocek, 1997). This would indicate that effects on rumen health were maintained through the ration change, perhaps as a direct result of the continuation and persistence of desirable feeding patterns and habits.

4.2 Future Research

Although this study was the first to show that diurnal feeding activity patterns and competitive behaviour can be learned from a young age, and that these behaviours may impact the health of growing dairy heifers, more work is needed to better understand the relationship between management and the development of these behaviours, as well as the influence of these behaviours on the health and welfare of these animals.

It was not possible to measure rumen pH in the study described in this dissertation. Measurement of such a rumen characteristic could have provided more
concrete evidence of greater incidence of SARA in the heifer fed the TDR. Thus, future research is needed to determine the effect of feed delivery method on rumen pH, as well as to determine if these feeding patterns, and their associated effects on rumen health, would continue through the development phase into the adult life of the dairy cows. Such persistence may help explain why we observe feeding patterns in dairy cows that result in SARA (DeVries et al., 2008), and thus the high incidence of SARA in dairy populations (Krause and Oetzel, 2006).

If competitive behaviour at the feed bunk, as observed in this study, persists into adult life it may result in further problems. For example, lameness due to increased inactive standing time, increased problems with digestive health due to slug feeding of the ration, and unbalanced intake of the ration by all animals, regardless of dominance status, have been observed in cattle (Krause and Oetzel, 2006; Gonzalez et al., 2008; Proudfoot et al., 2009). As such, future studies should evaluate how long this behaviour, when learned at a young age, persists. Furthermore, in an effort to prevent this behaviour from developing or to decrease its occurrence, further research is needed to consider how to minimize the competitive behaviour between animals at the feed bunk from a young age, perhaps by addition of barriers such as feed stalls, or by increasing feed bunk space or lowering stocking density (DeVries et al., 2004; DeVries and von Keyserlingk, 2006; Huzzey et al., 2006).

Even though we found that sorting behaviour developed initially, it had virtually disappeared by the end of the first 13 weeks of the experiment and continued to be negligible following the ration change, regardless of treatment. This result is interesting, since it indicates that the heifers were not learning and retaining the behaviour at that stage of their lives. Rather, it shows that they were able to acclimate to their ration, despite the different feeding methods. However, sorting behaviour may be detrimental to
the rumen health of adult, lactating dairy cattle (DeVries et al., 2008). It is important, therefore, to further understand the development of this behaviour and perhaps to discover why the behaviour extinguished in this feeding situation. Future research in this area, then, should focus not only on discovering at what point in the life of the animal this behaviour develops and what factors influence this development, but also should consider factors that influence the persistence or extinction of this behaviour.

Overall, further research on the effect of feeding method on the learning of feeding behaviour of dairy heifers should consider both earlier time periods in the life of the animal and also persistence of behaviour into adult life. Additionally, it is likely that there are multiple factors influencing the diet decisions and feeding behaviour of the animals at any particular time (i.e. social situation, housing, farm management, weather, etc.). It is important, therefore, for future research to identify these factors and how they may influence the learning and development of feeding behaviour. The aim of this research would be to develop feeding management strategies for growing dairy heifers that will best utilize their ability to learn proper feeding behaviours, patterns, and habits in an effort to prevent growth, production, and health problems. In better understanding the feeding behaviour and learning of young dairy heifers, we are more likely to find practical, effective solutions to minimize or eliminate the development of undesirable or detrimental feeding patterns. These desirable feeding behaviours, then, may persist into the adult life of the cow, aiding in maximizing the production potential and minimizing the health problems often experienced when entering the lactating herd.

4.3 Implications

Based on these results, it could be recommended that dairy producers feed their growing dairy heifers a TMR from a young age. This will enable these animals to
distribute their feeding activity throughout the day and also promote less competition for feed access. This may not only have immediate benefits on rumen health, but the persistence of these behaviours into maturity may help prevent other feeding-related or associated problems from developing (i.e. sorting, lameness, or metabolic disorders) when the animals enter the lactating herd.
CHAPTER 5: REFERENCES

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APPENDIX 1: SAS CODES

MIXED Models – Part 1

Percentage of heifers at the feed bunk analyzed using this model:

    proc mixed;
    class diet hour pen;
    model % eating = diet hour diet*hour / ddfm=kr;
    repeated hour/type=AR(1) sub=pen(diet);

Lying time and feeding time analyzed using this model:

    proc mixed;
    class diet week pen;
    model variable = diet week diet*week / ddfm=kr;
    repeated week/type=CS sub=pen(diet);

Displacements and peak feeding time analyzed using this model:

    proc mixed;
    class diet week pen;
    model peak variable = diet week diet*week / ddfm=kr;
    repeated week/type=VC sub=pen(diet);

DMI, fecal score, ADG, and sorting of long, medium, short, and fine particles analyzed using this model:

    proc mixed;
    class diet week pen;
    model variable = diet week diet*week / ddfm=kr;
    repeated week/type=AR(1) sub=pen(diet);

MIXED Models – Part 2

Percentage of heifers at the feed bunk analyzed using this model:

    proc mixed;
    class diet time pen;
    model % eating = diet time diet*time / ddfm=kr;
    repeated time/type=AR(1) sub=pen(diet);

Displacements, DMI, fecal score, and peak feeding time analyzed using this model:

    proc mixed;
    class diet week pen;
    model variable = diet week diet*week / ddfm=kr;
    repeated week/type=CS sub=pen(diet);
Feeding time and ADG analyzed using this model:

proc mixed;
class diet week pen;
model variable = diet week diet*week / ddfm=kr;
repeated week/type=VC sub=pen(diet);

Sorting of long, medium, short, and fine particles analyzed using this model:

proc mixed;
class diet week pen;
model variable = diet week diet*week / ddfm=kr;
repeated week/type=CSH sub=pen(diet);

Regression Models – Parts 1 and 2

Fecal score, feeding time, peak feeding time, and average daily gain regressed on heifer’s index of success using this model:

proc reg;
by diet;
model variable = index;